METALLURGIA

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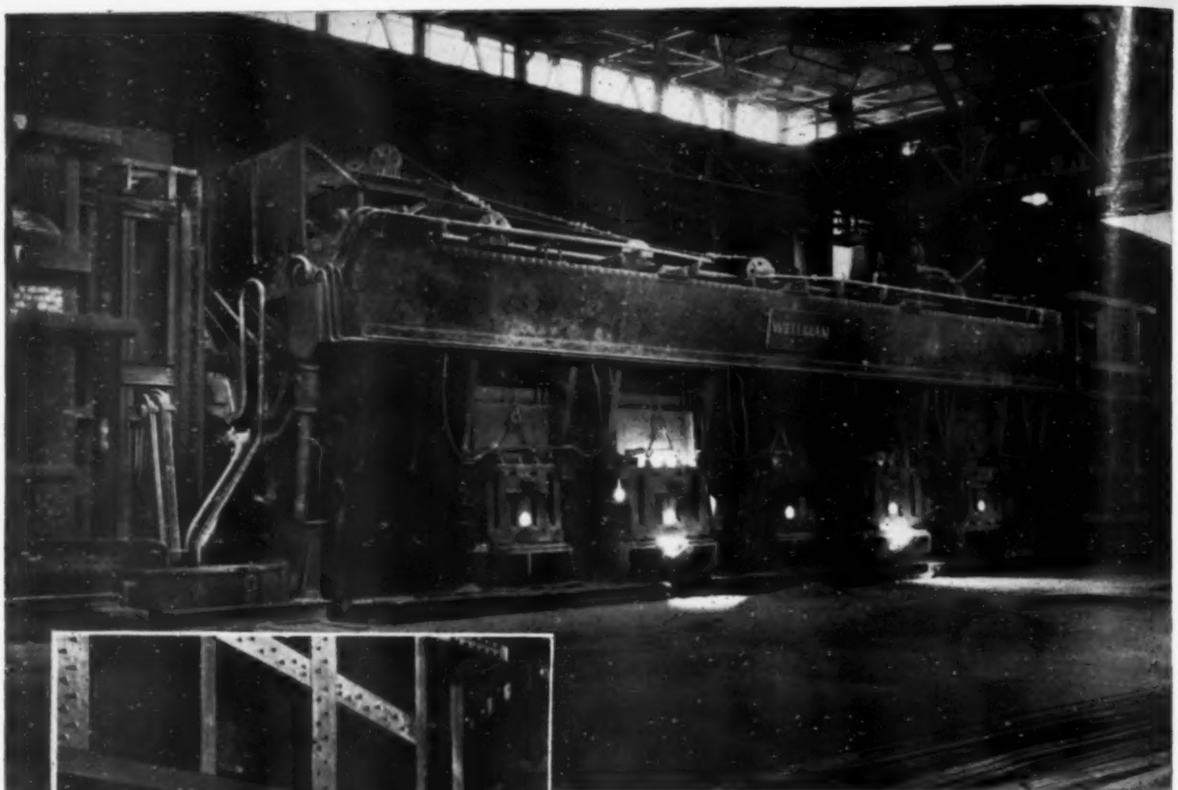

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Long-Term Scrap Prospects

THE long-term evolution of the supply of steel scrap in relation to requirements is a question of fundamental importance for the formulation of long-term investment policies, particularly in blast furnaces, coke ovens, iron ore mines and ore preparation equipment. It is not the overall level of iron and steel production or consumption as such that gives rise to scrap problems, so much as changes in the pattern of production, processing, trade and consumption of ferrous metals, which cause an altered balance between supply and demand.

In a recent United Nations report* factors affecting supply and demand in Europe (excluding the U.S.S.R.) are discussed. There are, of course, considerable country differences, but the relative scrap positions of the various European countries is reasonably clear. The general evolution of the pattern of production, trade, distribution and consumption of iron and steel follows broadly similar movements in most countries. Furthermore, intra-European trade in scrap is large enough to offset, at least to some extent, the more important country differences.

An increasingly large share of scrap consumption is made up by the requirements in steelmaking, which now take up no less than 70% of the total. Nearly another 20% goes into iron foundries, and most of the remaining 10% is charged into blast furnaces. The proportion of scrap consumed in blast furnaces, which represented 3% of pig iron output in 1913, increased to no less than 15% in 1950, owing to abnormal circumstances, and has subsequently fallen to 8%.

Thus, at present, no less than some 90% of the scrap consumed is used in sectors where scrap and pig iron are substitutes for each other, i.e. in iron foundries and steelworks. Output of pig iron cannot in the short run be rapidly increased, and, therefore, short-term flexibility in the use of either pig or scrap is only possible through variations in consumption of the latter. In the long run, the evolution of scrap supply is beyond the control of the steel industry, and flexibility has to be obtained by adjusting the supply of pig iron. European consumption of scrap by steelworks increased by a factor of about three-and-a-half between 1913 and 1955, during which period total ferrous metal output approximately doubled—a reflection of the greater relative expansion of open-hearth and electric steel production. Moreover, given a plentiful supply of scrap, it is obviously advantageous to use scrap as far as possible in order to save the heavy investment involved in increasing blast furnace, coke oven and iron ore capacity. As a result, in the long run, a scrap surplus cannot develop in practice, since any additional quantity of scrap available will tend to bring about the use of a greater proportion of scrap.

In the past, apart from exceptional circumstances such as the export of war scrap, European exports of pig iron and scrap have not been significant, and are accounted for by the disposal of temporary surpluses. In the years to come, it seems most unlikely that there can be any question of regular export from Europe of either pig iron or scrap.

There are four sources of scrap: (1) the iron and steel industry itself, which generates circulating scrap; (2) the industries consuming iron and steel as a raw material, which give rise to process scrap; (3) the "pool" of manufactured products containing iron and steel in use in the economy, part of which, through wear and obsolescence, gives rise to capital scrap; and (4) other regions from which scrap may be imported.

The availabilities of both circulating and process scrap in Western Europe are tending to increase proportionately faster than the output of ferrous metals. This is due largely to the fact that products with a high percentage of arising represent an increasing share of output, and that products are subjected to more extensive manufacturing operations. Furthermore, since direct exports of finished iron and steel represent a smaller proportion of output than before the war, the share of iron and steel production submitted to processing in Europe is increasing. This naturally means that a smaller proportion of total iron and steel output is available to be channelled back as capital scrap twenty years later. On the other hand, it also means that more scrap is channelled through areas where there is a high rate of recovery, since virtually all circulating and process scrap is recovered, and only a proportion of capital scrap can be collected.

Two factors tend to raise the supply of capital scrap in Western Europe, a tendency for the proportion of shorter-life manufactures to increase, and a tendency to produce a higher proportion of more easily recoverable products. This may seem somewhat surprising in view of the development of products such as tin cans. However, even in the United States products which are virtually irrecoverable represent a more or less constant proportion of total consumption, and output of easily recoverable durable consumer goods, such as cars and large household appliances, is increasing rapidly. The long-term capital scrap outlook therefore appears to be reasonably favourable.

Owing to the low rate of consumption of iron and steel in the 1940's, however, capital scrap arising in Western Europe seems likely to be running at a rather low level in the 1960's, and as production only really recovered from the slump of the 1930's a year or two before World War II, capital scrap supplies are likely to continue to be limited for some years to come.

The prospects of meeting fully Europe's deficiencies from the United States appear to be somewhat slender, for, although the availability of scrap in the United States is proportionately higher than in Europe, this is offset by a proportionately higher and rising demand. The high export availabilities of scrap from the United States in the 1930's can now been seen as a temporary

* "The European Steel Market in 1955." Prepared by the Secretariat of the Economic Commission for Europe, and obtainable from H.M. Stationery Office. (Price: 5s. 6d.)

phenomenon, due on the one hand, to the fact that World War I did not check economic activity, and on the other, to the relatively low steel output in the 1930's. In addition, there is little likelihood of scrap being available for export from the U.S.S.R. and Eastern Europe for an indefinite period.

From these considerations, it follows that a high rate of expansion of blast furnace facilities is required to cope with the scrap deficiencies which appear inevitable up to the late 1960's.

Personal News

Mr. G. N. F. Wingate, who has been appointed Director and General Manager of Distington Engineering Co., Ltd., has for the last five years been at the Steel, Peech and Tozer, Rotherham, branch of The United Steel Companies, Ltd, where he has been Works Manager (Services).

Mr. J. Jack and Mr. J. H. Patchett have been appointed Directors of Dorman, Long and Co., Ltd. Mr. W. L. Fletcher, Managing Director of Tees Side Bridge and Engineering Works, Ltd., has been appointed a Special Director of Dorman Long.

Mr. E. T. Gill has joined the staff of the Development and Research Department of The Mond Nickel Co., Ltd., as Development Officer for Constructional Alloy Steels. He is taking up the position which became vacant when Mr. L. W. Johnson was appointed Assistant Manager of the Department.

The British Aluminium Co., Ltd., announce that Mr. P. Ralph has been appointed Vice-President of Aluminium Transatlantic, Inc. He leaves for New York this month. Mr. R. A. Martin has been appointed Manager of British Aluminium's Scottish Branch Sales Office, in succession to Mr Ralph.

Sir Charles Lillicrap, K.C.B., M.B.E., has been elected President of the Institute of Welding for 1956/57, and was installed at the Annual General Meeting of the Institute on July 19th. Mr. J. Strong, a Director of British Oxygen Engineering, Ltd., has been elected Vice-President.

English Steel Corporation, Ltd., announce the appointment of Mr. J. T. W. Dewar as an additional Director of the Company. Mr. Dewar is Deputy Managing Director of Firth-Vickers Stainless Steels, Ltd., and Managing Director of Shepcote Lane Rolling Mills, Ltd., both of which appointments he retains.

British Insulated Callender's Cables, Ltd., announce the appointment of Mr. R. L. Packer as Regional Manager, North-West Region, in succession to Mr. J. L. Morley who retired at the end of July. Mr. Packer has been succeeded as Branch Manager, London, by Mr. R. E. Prickett, who, in turn, is succeeded as Branch Manager, Brighton, by Mr. G. F. Huddleston.

Mr. L. Redshaw has been appointed an additional member of the Board of Directors of Vickers-Armstrongs (Shipbuilders), Ltd. He retains his present office of Shipbuilding General Manager.

Mr A. G. E. Robiette has been awarded the degree of Doctor of Science by the University of Wales.

Dr. Clyde Williams, President and Director of Batelle Institute, is to address the Trade Promotion Conference and Second Annual Dinner of the Welsh Economic Development Council at Cardiff, on October 12th, 1956.

Mr. W. A. Coates retired from the Board of Metropolitan-Vickers Electrical Co., Ltd., on July 4th. He will continue as Commercial Consultant to the Managing Director until the end of the year. Mr. Coates has also resigned from the Boards of the following M-V subsidiary companies: Metropolitan-Vickers-GRS, Ltd., Newton Victor, Ltd., and Sunvic Controls, Ltd.

The Steel, Peech and Tozer Branch of The United Steel Companies, Ltd., announce the following appointments: Mr. C. H. Hayter as Works Manager (Services); Mr. N. H. Bacon as Superintendent, Ickles Departments; Mr. W. Ash as Chief Works Metallurgist; and Mr. H. A. Longden as Assistant Chief Works Metallurgist.

English Steel Corporation, Ltd., Sheffield, announce a number of appointments to the Boards of its wholly-owned subsidiary companies: Mr. G. Craven, D.S.C., a Director of English Steel Export Corporation, Ltd., has been made a Director of English Steel Forge and Engineering Corporation, Ltd., responsible for commercial matters; Mr. C. Muirhead, O.B.E., Director of English Steel Castings Corporation, Ltd., and English Steel Spring Corporation, Ltd., and Special Director of English Steel Corporation, Ltd., and Mr. E. W. Greaves, London representative for railway materials, have been appointed Directors of David and Lloyd (1955), Ltd., designers of cast steel side frames and bolsters, unit brake beams, snubbers and similar appliances for railway rolling stock.

Mr. B. W. Kerrigan is appointed Secretary of the Institution of Mining and Metallurgy, and takes up his duties at the beginning of this month.

Mr. F. W. Martin has been appointed Deputy Chairman of Tube Products, Ltd., Oldbury. On taking up this appointment, he has relinquished his Joint Managing Directorship of Tube Products, and has been succeeded therein by Mr. E. D. E. Andrews. Mr Andrews has relinquished his appointment as Joint Managing Director of Accles and Pollock, Ltd., but remains a Director of that Company. Mr. Andrews is also a Director of Tube Investments, Ltd.

Mr. F. D. Hucklesby has been appointed Superintendent of the Process Development Section at British Oxygen's Sales Technical Service Department at Cricklewood.

Mr. C. J. Atkins, Sales Director; Mr. F. W. Goodge, Contracts Director; and Mr. S. Hudson, Director and London Works Manager; have been appointed Directors of Keith Blackman, Ltd. Mr. A. H. Woodley has been appointed Sales Manager.

Obituary

We regret to record the death of Mr. N. D. Ridsdale on Tuesday, July 17th, 1956, following a short illness. Mr. Ridsdale was well known in metallurgical analysis circles, particularly for his work on the provision of standard samples of steels, non-ferrous metals, fluxes, slags, etc., for use in connection with chemical and physical methods of analysis. Together with his father, the late Mr. C. H. Ridsdale, he founded Ridsdale & Co., analysts, in 1911, and since its incorporation in 1935 he has been Managing Director of Ridsdale & Co. Ltd., and of the newly formed Bureau of Analysed Samples Ltd. He is succeeded as Managing Director by his son, Mr. P. D. Ridsdale.

The Effect of Nickel Content and Furnace Atmosphere on the Scale Formed on Nickel Steels

By K. Sachs, M.Sc., Ph.D., A.I.M.

The inner layer of the scale on nickel steels contains nickel-rich metallic particles entangled with the wüstite. The amount of metal in the scale diminishes with increasing partial pressure of oxygen in the oxide and with falling nickel content. The furnace atmosphere and the scale thickness determine the partial oxygen pressure at various levels in the scale, and thus the nickel content of the metal phase.

THE effect of an alloying element on the oxidation of the base metal will depend on the relative stability, the mutual solubility, and the equilibrium relations of the oxides formed. The general case of a more readily oxidisable addition is exemplified in alloys of iron, nickel, or copper with varying contents of silicon, chromium or aluminium, which have been studied extensively. Theoretical work on more noble alloying elements, e.g., in copper-gold, nickel-palladium, nickel-platinum alloys has also been published,[1, 2] although it is less voluminous. Nickel steels, which have been the subject of a number of investigations within the last ten years, notably by French authors,[3] do not fall into either of these classes because nickel is not a noble metal, but nickel oxide is unstable in the presence of iron oxides below an oxygen content of 28%.[4] As a result, nickel-iron alloys form a sub-scale of wüstite globules in the metal, while the scale on low nickel steels contains metal particles enriched in nickel.[4, 5, 6] The characteristic structure of the innermost scale layer has been studied in some detail, and results showing the influence of variation in nickel content, the atmosphere in which the scale is formed, and the thickness of the scale, are presented in this paper.

Experimental Procedure

The steels used for this work were melted in a 14 lb. high frequency induction furnace from raw materials of fairly high purity. The melts were based on Doncaster iron, which contains small amounts of chromium and copper; the composition of the various steels is given in Table I. For the study of the effect of furnace atmosphere, small specimens were oxidised in a tube furnace; most other scaling treatments were carried out in gas-fired furnaces, and the severity of oxidation could be reduced by placing a small Inconel box over the specimen. The top of the box was welded to one side only, leaving a narrow gap to allow limited circulation of the furnace atmosphere round the specimen. Comparison of the structure obtained on freely exposed specimens and those scaled under boxes showed quite clearly that the partial pressure of oxygen was considerably lower inside the boxes. Preparation of specimens for micro-examination presented some difficulty, owing to the porous and brittle character of the scale; the specimens were mounted in Diakon before being sectioned, so that the scale was held on all sides during the sawing operation.

In the study of the effect of nickel content and furnace atmosphere, steels with nickel contents of the order generally prevailing in commercial compositions were compared with mild steel, on the one hand, and a nickel-iron alloy on the other. Oxidation was carried out in mixtures of commercial oxygen and nitrogen. Precise knowledge of the composition of the atmosphere does not imply that the partial pressure of oxygen in the scale is known. Scaling in severely oxidising atmospheres leads to a thick scale deposit, which exercises a protective effect on the metallic core. It was recognised that the comparison of the structure at the scale/metal interface of a steel scaled in different atmospheres for a given time would reveal the combined effect of furnace atmosphere and scale thickness, and this had to be taken into account in the interpretation of the results.

TABLE I.—ANALYSIS OF STEELS.

Lab. Mark	C (%)	Si (%)	Mn (%)	S* (%)	P* (%)	Ni (%)	Cr (%)	Sb (%)	Al (%)
JXU	0·01	0·25	0·38	0·005	0·03	—	—	—	—
JXY	0·07	0·24	0·42	0·005	0·03	1·53	—	—	—
LTY	0·06	0·12	0·22	0·005	0·03	1·52	—	—	—
LTZ	0·04	0·08	0·15	0·005	0·03	2·92	—	—	—
KFF	0·06	0·23	0·47	0·005	0·03	1·64	—	—	0·2
LNP	0·33	0·23	0·43	0·012	0·020	2·98	0·09	0·09	—

* Nominal.

Specimens were prepared from steels JXU (0% Ni), LTY (1½% Ni), LTZ (3% Ni), (analyses in Table I), and from a commercial nickel-iron alloy, Nilo 43, containing 0·06% C. and 42·9% Ni. The specimen dimensions were ¾ × ½ × ¼ in.; all surfaces were ground, and an ⅛ in. hole was drilled through the specimens so that they could be wired to a jig. Oxidation, for 7 hr. at 1,200° C., was carried out in a long tube of glazed silica inside a platinum-wound alumina furnace tube.

Commercial oxygen, nitrogen, and compressed air were used to make the following atmospheres: oxygen; air; nitrogen with 5% oxygen; nitrogen with 1% oxygen; and nitrogen. The small amount of oxygen present in commercial nitrogen (about 0·2%) was sufficient to form an adequate oxide layer at 1,200° C. In the course of calibrating the constriction flow-meters, it was found that a rate of flow of about 36 cc./sec. was most convenient to maintain. Such a value at room temperature corresponds, at 1,200° C., to a flow of gases past specimens in a 1⅞ in. diameter tube at the rate of about 20 ft./min.—well above the "critical" rate of flow determined by Upthegrove,[7] i.e., 10 ft./min.

The specimens were wired to a jig consisting of two Brightray end rings, joined by four Brightray rods. The jig was quite rigid at 1,200° C., and the specimens were spaced out along it in such a way that there was free access of gas to all surfaces, while the jig was free to slide in the silica tube. After the scaling treatment, the entire jig was plunged into a bucket of water. It was found that the outer layers of the scale tended to split off, but it was possible to find fields on all micro-sections which illustrated all portions of the scale; the main point of interest, is, in any case, the inner part of the

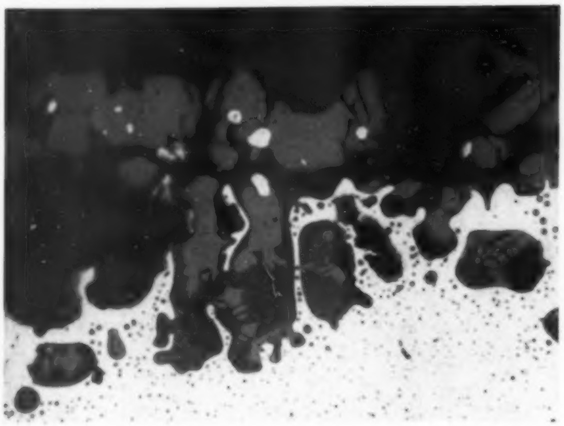

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Fig. 1.—Nickel free steel (JXU) heated in an atmosphere of nitrogen + 1% oxygen. × 300

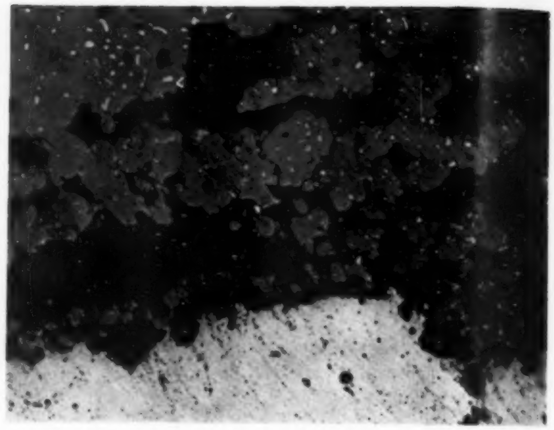

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Fig. 2.—1½% nickel steel (LTY) heated in an atmosphere of oxygen. × 300

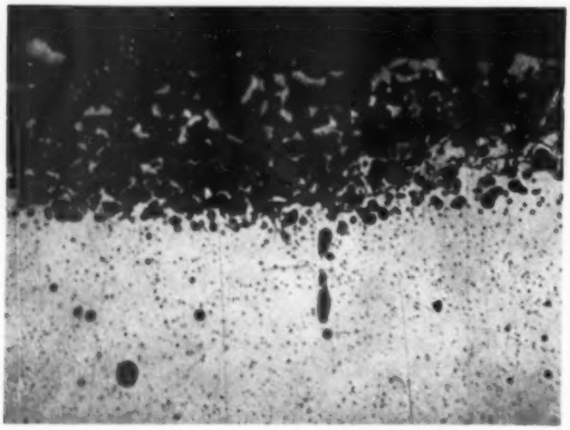

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Fig. 3.—1½% nickel steel (LTY) heated in an atmosphere of nitrogen + 1% oxygen. × 300

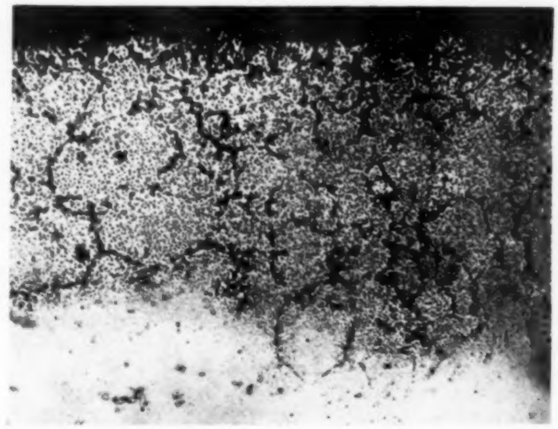

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Fig. 4.—Nilo (43% nickel) heated in an atmosphere of oxygen. × 150

Figs. 1–4.—Typical structures of the inner scale layer formed in various atmospheres on steels of different nickel content in 7 hours at 1,200° C.

scale, which was substantially preserved in spite of the quench.

Scales Formed in Controlled Atmospheres

The thickness of the scale was measured on the travelling stage of a Zeiss photo-microscope, and the results set out in Table II were obtained. In general, higher nickel contents resulted in thinner scales, while more oxidising atmospheres led to greater scale thicknesses, but with scales less than 0·5 mm. in thickness, differences in experimental conditions had no significant effect.

Micro-examination of the inner scale layer revealed that the amount of metal entangled in the scale diminished with increasing severity of oxidation and with lower nickel contents. More severe oxidation led to a thicker scale, and thus to a shallower concentration gradient in the inner layer; this tends to even out the effect of variations in furnace atmosphere, which is, however, sufficiently pronounced to be clearly revealed in Figs. 2 and 3, showing a 1½% nickel steel scaled in oxygen, and in nitrogen with 1% oxygen, respectively. The effect of nickel is illustrated by comparison with a specimen of mild steel (JXU) scaled in nitrogen and 1% oxygen (Fig. 1).

The structures produced in the 43% nickel-iron alloy as a result of oxidation in various atmospheres are qualitatively different. There is a narrow scale layer on the surface of the specimen and a wide layer of subscale, showing intergranular oxide penetrating far into the metal and numerous oxide globules in the grains.

TABLE II.—THICKNESS OF SCALES FORMED IN CONTROLLED ATMOSPHERES.

Atmosphere	Steel			
	JXU (0% Ni)	LTY (1½% Ni)	LTZ (3% Ni)	Nilo (43% Ni)
	mm.	mm.	mm.	mm.
100% Oxygen	2·99	2·95	2·64	0·295
20% Oxygen	1·46	1·40	0·98	0·32
5% Oxygen	0·96	0·82	0·53	0·31
1% Oxygen	0·90	0·68	0·56	0·15
Nitrogen	0·56	0·46	0·55	0·24

TABLE III.—METAL CONTENT OF SCALE IN STRUCTURE—PER CENT.

Atmosphere	Steel			
	JXU (0% Ni)	LTY (1½% Ni)	LTZ (3% Ni)	Nilo (43% Ni)
100% Oxygen	0	9	25	53
20% Oxygen	3	12	19	—
5% Oxygen	—	18	25	58
1% Oxygen	14	22	27	76
Nitrogen	17	26	22	75

This sub-scale is illustrated in Fig. 4 for the specimen scaled in oxygen. The sub-scales on specimens treated in less severely oxidising atmospheres were somewhat thinner but similar in structure, with the globules becoming more prominent at the expense of the intergranular oxide.

An attempt was made to correlate the variation in structure with the systematic alteration in the experimental conditions. A graticule, about 1½ in. square, with each side divided into ten equal parts, the whole ruled on a glass plate, was placed in various positions on the photo-micrographs, and the number of squares filled by metal was counted; this gave the metal content in per cent. This is necessarily a very crude attempt at assessing the structure: it is subject to inaccuracies resulting from variations in the amount of metal present at different depths in the scale; from geometrical factors due to the shape of the metallic filigree in the scale; from differences in density of the scale, particularly where the scale is porous; and from the human factor, especially when the magnifications of the photographs vary. The results of at least three countings for each photograph were averaged, and the results are set out in Table III. The figures for the 3% nickel steel LTZ in oxygen and nitrogen without additions seem anomalous.

The observations are summarised in Fig. 5, showing the atmospheres and nickel contents required to give scales having equivalent amounts of metal entangled in them. Naturally, this graph is only valid for fresh specimens scaled for 7 hours at 1,200° C. The graph was prepared by plotting the figures in Table III against the nickel content and against the furnace atmosphere, interpolating between experimental points to give smooth curves; these plots were then combined in Fig. 5. which must be regarded solely as giving a qualitative indication of the effect of the experimental variables. A number of interesting conclusions can be drawn :—

(1) Even a mild steel must be oxidised in an atmosphere containing over 20% oxygen in order to remove all metal from the scale.

(2) Once the structure contains more than about 50% metal, considerable variations in nickel content or atmosphere have little effect on it. This may serve as a convenient criterion for distinguishing between sub-scales and oxides with entangled metal.

(3) Atmospheres with more than about 20% oxygen, and nickel contents above about 20–30%, have relatively little influence on the structure of the scale. This may help to establish the nickel content at which a proper sub-scale appears.

(4) At high nickel contents the curves are spaced wider apart; i.e., the effect of variations in nickel content is less pronounced.

(5) The curvature is greater at low oxygen contents, i.e., the effect of variation in atmosphere is greater at low oxygen concentrations.

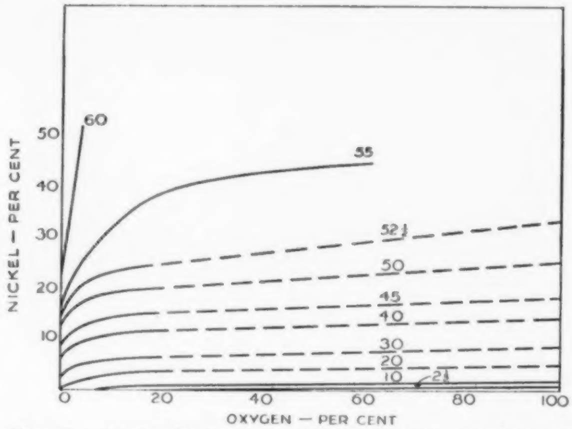

Fig. 5.—Atmospheres and nickel contents required to produce structures with given metal contents in the inner scale layer.

(6) If the amount of metal in the scale is relatively small, (i.e., low nickel content, severe oxidation) nickel has most effect in modifying the structure; if it is great (high nickel content, low partial pressure of oxygen) the atmosphere has most effect.

Scales Formed in Industrial Atmospheres

The effect of variation in the furnace atmosphere could also be demonstrated by a comparison of scales formed on specimens freely exposed to the atmosphere in a small gas-fired furnace with those formed on specimens oxidised under a small protecting box which limits access of gases to the specimens, and thus lowers the partial pressure of oxygen. This simple method of modifying the structure of the inner scale layer lends itself to a study of the variation with time of the influence of furnace atmosphere.

The exact composition of the atmosphere surrounding the specimens is not known in either case. The conditions of combustion required to maintain the temperature were probably oxidising, and it is likely that a small amount of free oxygen was left in the gases under the protecting box. The experiments were carried out with Birmingham town's gas, which contains about 20 grains of sulphur per 100 cu. ft., and there was, in consequence, a significant concentration of sulphur dioxide in the furnace atmosphere (*cf* Ref. 8).

The structures produced in the scale on a 1½% nickel steel in about 2 hours at 1,250° C. are shown in Figs. 6 and 7, and it is evident at a glance that much more metal is entangled in the scale formed under less severely oxidising conditions. The effect of scale thickness is demonstrated in Fig. 8, illustrating the structure produced by free exposure for 24 hours at 1,250° C.

In order to distinguish between the effects of time of oxidation and scale thickness, an experiment was carried out in which the furnace atmosphere around specimens with thick scales was modified for a relatively short time. Specimens KFF 3, 4 and 5 were placed on a 1 in. high Inconel tray, covered with protecting boxes and inserted into a hot gas muffle at about 1,250° C. After 7¼ hours, the protecting box was removed from specimen KFF 5 and oxygen was directed in a jet onto the specimen through a sillimanite tube inserted through the furnace door. After a further 15 minutes, the protecting box

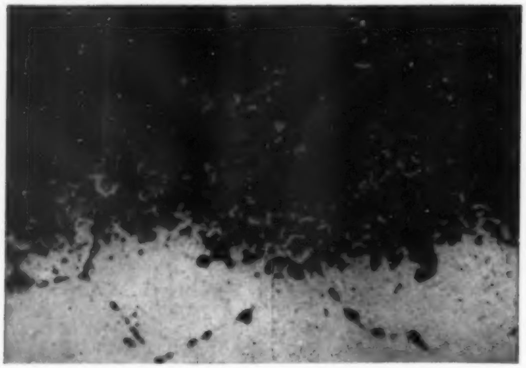

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Fig. 6.—Heated 2 hours, freely exposed to the furnace atmosphere. × 300

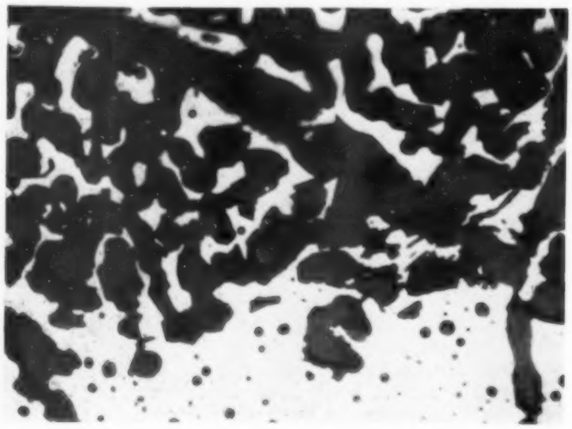

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Fig. 8.—Heated 24 hours, freely exposed to the furnace atmosphere. × 300

was replaced on KFF 5 and the box from KFF 4 was removed ; the oxygen jet was then directed at the latter specimen. A quarter of an hour later all three specimens were removed from the furnace and cooled rapidly on a cold steel plate.

Making an allowance of 15 minutes for the time taken to reach the furnace temperature KFF 3 was scaled under a protecting box for 7½ hours, KFF 4 was scaled under a box for 7¼ hours and oxidised severely for a quarter of an hour, while KFF 5 was scaled in a weakly oxidising atmosphere for 7 hours, oxidised severely for a quarter of an hour, and then returned to a weakly oxidising atmosphere for a quarter of an hour. Observation of the specimens in the furnace showed that the oxygen jet had a slight cooling effect. The end of the tube was held about 3 in. from the specimens, and there is no doubt that the atmosphere immediately surrounding the specimen was greatly enriched in oxygen.

The structure of the scale on KFF 3, shown in Fig. 9, has all the features expected in a specimen scaled for a long period in a rather weakly oxidising atmosphere. A filigree pattern of metallic films close to the core merges into a structure consisting of small discrete particles of metal. The effect of rapid oxidation for a quarter of an

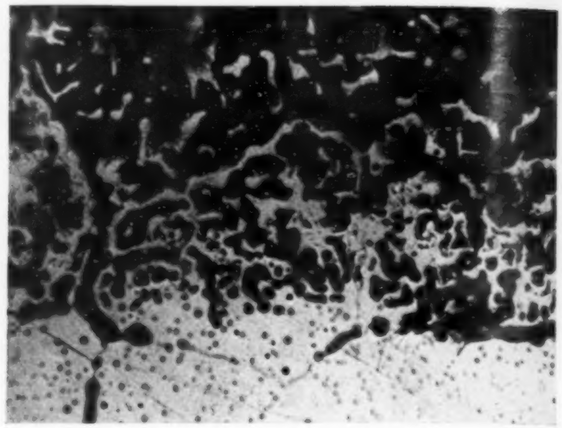

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Fig. 7.—Heated 2 hours, exposed under a small protecting box. × 300

Figs. 6–8.—1½% nickel steel (JXY) scaled in a gas-fired furnace at 1,250° C.

hour is shown in Fig. 10. Some metallic particles have remained, but the intermingled metal in the scale has considerably diminished in quantity. In Fig. 11, illustrating the specimen which had a short period of normal scaling after the rapid oxidation treatment, the metallic particles have re-appeared in almost the same profuseness in which they were produced by the original scaling treatment.

In order to make sure that the particles in KFF 5 were formed in the scale already existing on the specimen, and not by an advance of the scale into the metal during the final treatment under the protecting box (¼ hour), specimen KFF 6 was scaled under a box for 30 minutes at 1,250° C. The nickel particles formed as a result of this treatment were much smaller and less numerous than those found in specimen KFF 5. It appears, therefore, that the metal particles formed in the scale on nickel steels not only vary in profusion with the degree of oxidation of the atmosphere prevailing throughout the formation of the scale, but are considerably influenced by short periods in different atmospheres. The experiment also demonstrates the effect of change in furnace atmosphere on scales of equal thickness.

The profound effect of the furnace atmosphere, even on the scale found on mild steel, was revealed by imposing an extreme change in atmosphere. Specimen JXU 20 was placed in an electric furnace at 1,150° C. for 46 hours. The atmosphere was air, i.e., severely oxidising. The specimen was cooled on a steel plate and then placed in a heat treatment box, 8 × 4 × 4 in. It was covered by a small protecting box to maintain a free space immediately around the specimen ; the heat treatment box was then filled with cast iron iron turnings and replaced in the electric furnace at 1,150° C. for 22 hours. Air had little or no access to the specimen and a small amount of carbon monoxide may have been present in the atmosphere from the carbon in the cast iron ; thus, the partial pressure of oxygen surrounding the specimen was very low indeed. A corner of the metallic core is shown in Fig. 12. The structure is characterised by the presence of a continuous metallic layer separated from the core by coarse oxide inclusions which forms an almost continuous film.

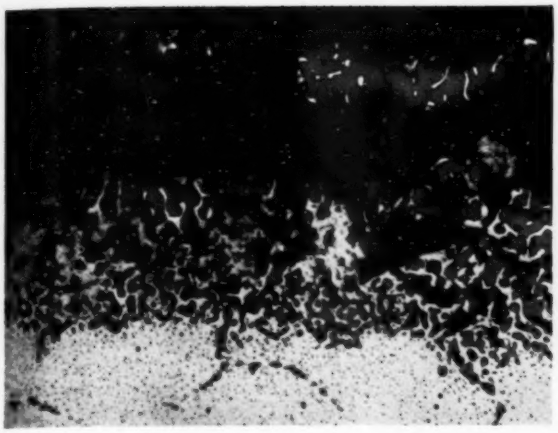

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Fig. 9.—Specimen KFF3, heated 7½ hours under a protecting box. ×200

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Fig. 10.—Specimen KFF4, heated 7¼ hours under a protecting box, followed by ¼ hour in an oxygen-enriched atmosphere. × 200

Figs. 9–11.—1½% nickel steel (KFF) scaled in a gas-fired furnace at 1,250° C., with short treatments in modified atmospheres.

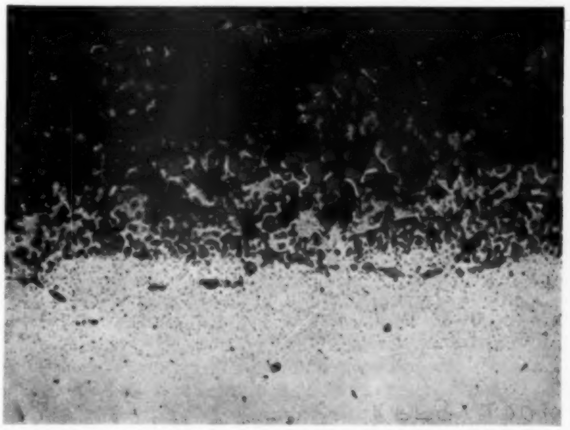

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Fig. 11.—Specimen KFF5, heated 7 hours under a protecting box, followed by ¼ hour in an oxygen-enriched atmosphere, followed by ¼ hour under the protecting box. × 200

Further out in the scale, metal has been precipitated in the form of thin filaments, as illustrated in Fig. 13. It appears, therefore, that iron can be precipitated in the scale formed on mild steel by suitable adjustments of furnace atmosphere.

Concentration of Nickel and Antimony in the Metal Particles

The metal particles in the inner layer of the scale are richer in nickel than the original steel, and the oxide surrounding them cannot dissolve nickel. This is generally attributed to the fact that nickel is less readily oxidised than iron, and similar concentration in the metal particles would be expected with many other elements,[9] e.g., cadmium, cobalt, antimony, lead, bismuth, copper, silver, and gold. It is known that copper

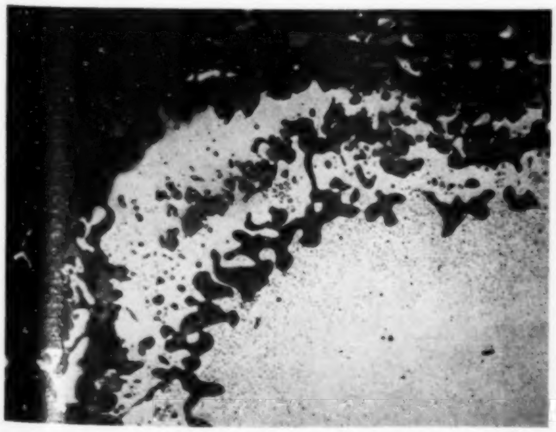

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Fig. 12.—Corner of metallic core. × 50

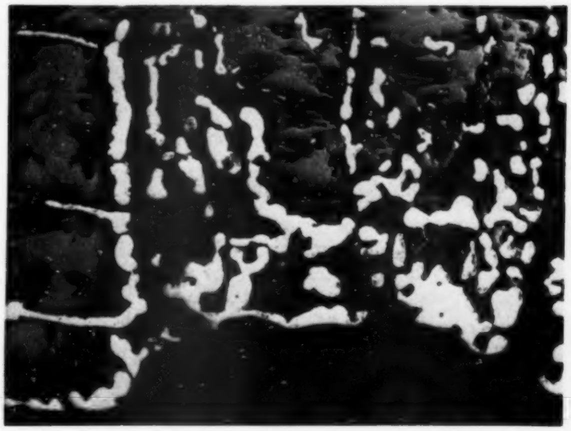

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Fig. 13.—Precipitated iron in the scale. × 50

Figs. 12–13.—Nickel free steel (JXU) heated 46 hours in air at 1,150° C., followed by 22 hours in a closed box, packed in cast iron turnings, also at 1,150° C.

TABLE IV.—NICKEL AND ANTIMONY CONTENTS OF SCALE ON STEEL CONTAINING 3% NICKEL AND 0·09% ANTIMONY.

	Nickel		Antimony		
	Content (%)	Enrichment Factor	Content (%)	Enrichment Factor	Ratio Ni/Sb
Original Steel (LNP)	2·98	—	0·09	—	33·1
Inner Scale Layer	6·69	2·24	0·176	1·95	38·0
Magnetic Fraction	8·05	2·70	0·324	3·6	27·8

tends to concentrate in metallic particles close to the surface of the core.[10] The low melting point of these copper-rich particles may cause hot shortnesss of the steel; the particles melt and the liquid phase attacks the surface and may cause intergranular penetration under the stresses imposed by hot working. The addition of nickel to such steels allows nickel to concentrate in the metal particles and raise their melting point.[11]

In the present work, an attempt was made to ascertain whether antimony concentration can occur in the metal particles embedded in the scale. Two pieces of steel LNP (3% Ni, 0·09% Sb) were placed in a small open box and kept in an electric furnace for a week while various heat-treatments at temperatures in the region of 1,050–1,150° C. were carried out. The three scale layers were broken away and the thick, adherent, inner layer was ground down to about 175 mesh. A sample of this layer of the scale was submitted for analysis, while the rest of the layer was separated into two fractions with a magnet, and the magnetic powder analysed.

Of the phases normally present in scales on nickel steels, ferric oxide and wüstite are non-magnetic, while magnetite is ferro-magnetic; the metallic material is also strongly magnetic, except at certain nickel contents. Ferric oxide should not be present in the inner scale layer, and magnetite should only exist to the extent that wüstite has undergone eutectoid breakdown. The magnetic fraction of the scale would be expected to consist of iron alloyed with nickel, traces of magnetite, and of mechanically entrapped wüstite.

The nickel and antimony contents can be seen in Table IV. Antimony had accumulated in those fractions of the scale which had been enriched in nickel, and the enrichment factors were of the same order of magnitude. It seems reasonable to suppose, therefore, that the metallic filigree in the scale which is known to be enriched in nickel is also richer in antimony than the original steel.

Discussion

At any temperature the amount of metal embedded in the inner scale layer of nickel steels depends on the nickel content and on the severity of oxidation; the latter varies with the furnace atmosphere and with the thickness of the scale. A change of short duration in the atmosphere surrounding the steel is sufficient to modify the structure. It would appear, therefore, that it is the partial pressure of oxygen in the oxide which determines the amount of metal in the scale at any point. The inner layer of a stable scale deposit of reasonable thickness will not contain enough oxygen for any nickel to be in solution in the oxide, so that all the nickel must be in the metal phase. The amount of metal in the scale is far in excess of the nickel content, and it can be concluded that variation in the partial pressure of oxygen only affects the amount of iron present in the metallic phase. Thus severe oxidation yields few metal particles of relatively high nickel content, mild oxidation results in a structure with more metal of lower nickel content entangled in the oxide. The amount of metal in the scale also varies with the nickel content of the steel. The partial pressure of oxygen in the oxide determines the composition of the metal particles, and a higher nickel content leads to the presence of more metal particles of the appropriate composition.

It is impossible to use the term equilibrium in discussing growing scales with a continuously varying concentration gradient, but it appears that there is a metastable relationship between the wüstite of the inner scale layer and the metal embedded in it, so that changes in the partial pressure of oxygen in the wüstite lead to corresponding changes in the nickel content of the metal, and, therefore, in the amount of metal embedded in the scale. This view is consistent with the observation, recorded above, that nickel has a more profound effect on scale structures with relatively few, and therefore nickel-rich, particles, while the atmosphere is the more decisive factor in scales with a large amount of metal rich in iron which enters the scale or metal phase according to the partial pressure of oxygen. It has been shown that antimony concentrates in the metal particles embedded in the scale in much the same proportion as nickel. Presumably, scale formed on antimony steels under conditions of severe oxidation would contain relatively few particles rich in antimony, while scale formed by mild oxidation would contain more metallic particles of lower antimony content.

Acknowledgments

The author is indebted to the Mond Nickel Co. Ltd., for permission to publish this paper. Some of the experiments described in it arose out of the results of work carried out by colleagues in the Development and Research Laboratory of that Company.

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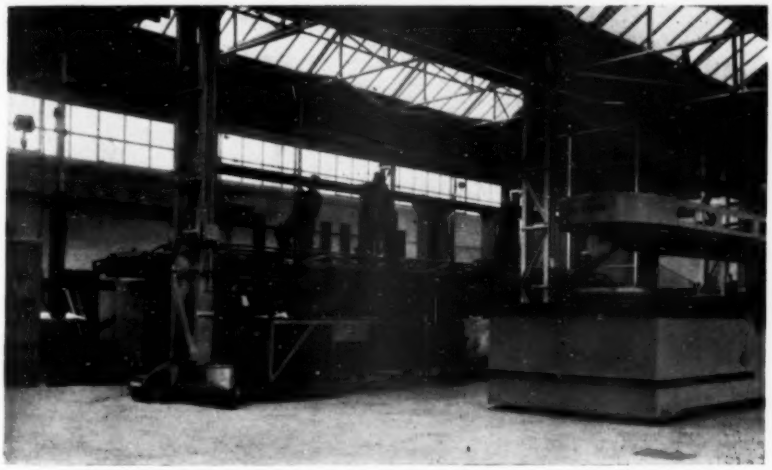
New Tunnel Kiln at Worksop

A NEW tunnel kiln, to be known as the Kirkby Kiln, was recently put into operation at the Worksop Plant of General Refractories, Ltd., for the burning of basic refractories. The kiln is capable of firing at temperatures up to 1,650° C., and has a total overall length of 346 ft. It will hold 56 cars, each with a capacity of approximately 5 tons, giving a weekly output of 600 tons.

The kiln is of the latest design and is fired by 950 seconds fuel oil through a total of 40 Schieldrop P type burners situated in the kiln side walls. All the refractories were supplied from various works of the G.R. Group, and those in the hot zone are of G.R. Sillmax 63/100, a special grade of Sillimanite brick.

The kiln is housed in a long, wide-span steel-framed building in which car loading, unloading and palletisation facilities have been amply catered for in a manner which will reduce the handling of the refractories to a minimum. The whole project was completed to an overall scheme by General Refractories, Ltd., who placed the contract for the design and construction of the tunnel kiln with the British Ceramic Service Co., Ltd.

Electro-Chemical Engineering Company's New Factory at Woking



Efco-Udylite automatic plating machines under construction.

THE increasing activities of the Electro-Chemical Engineering Co., Ltd., and the expansion of the Company's business during the last few years, have now made it essential that all activities should be operated from one factory. Previously, complete manufacture had been carried out at the EFCO works at Burton-on-Trent and by various sub-contractors, but the new factory on the Sheerwater Trading Estate, Woking, which was opened recently, makes provision for the carrying out, under one roof, of engineering work, chemical mixing and packaging, and the laboratory analysis of process solutions. The engineering activities of the Company comprise the assembly and mechanical testing of Efco-Udylite automatic machines ; it is also planned to manufacture other products at present being sub-contracted. The chemical products which are mixed and packaged at the new factory, comprise the range of chemicals used in the various Efco-Udylite processes, while the routine analysis of customers' solutions can be carried out at regular intervals as part of the free service given. In the development laboratory and demonstration plating shop, new processes can be tried out and demonstrated.

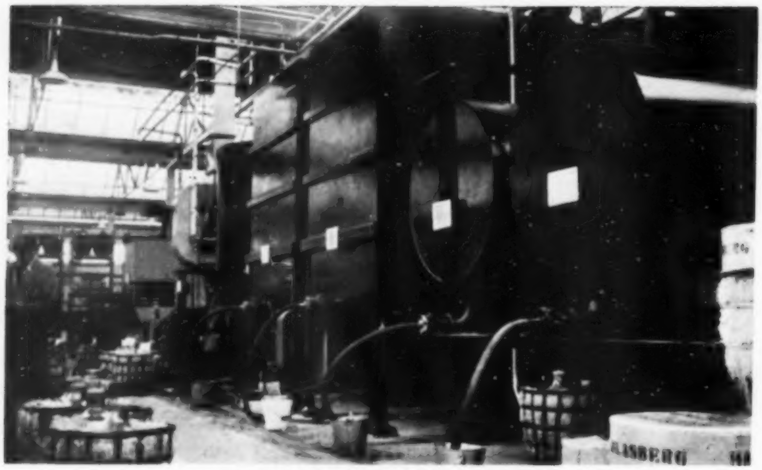
The Electro-Chemical Engineering Co., Ltd., was formed in 1939 as a wholly-owned subsidiary of Electric Furnace Co., Ltd., now EFCO, Limited, and has previously been situated at Weybridge, Surrey. During the war its activities were concerned with the design and manufacture of automatic pickling machines for ordnance work, and after the war these activities were extended into the production of general continuous pickling and electroplating plant. One such installation for Maclean & Co. (Metal Windows), Ltd., at Hamilton, Lanarkshire, is still probably the largest electroplating installation in Europe.

Manufacturing Agreements

In 1947, a long term agreement was made with the Udylite Corporation of Detroit (the largest suppliers of electroplating equipment and processes in the world) which put Electro-Chemical Engineering Co., Ltd., in the position, not only of being able to build automatic machines of the " return type " to Udylite designs, but also to build fully immersed electroplating barrels and other equipment, and—even more important—to supply the well-known Udylite bright plating processes, comprising bright nickel, bright zinc and bright cadmium.

In 1954, an agreement was made with Solventol Chemical Products, Inc., Detroit, under which the Company was licensed to manufacture Di-Phase cleaning equipment and cleaning processes. A Metal Cleaning Division was accordingly formed to handle Di-Phase equipment, automatic trichlorethylene degreasers, and ultrasonic cleaning equipment, for which the Company has a selling arrangement with a Swiss firm.

Chemical section, showing export packages in foreground.



Chemical mixing equipment.

Post-War Progress

The rapid development of the Company's business during the last ten years has resulted in a ten-fold increase of sales turnover. The greater awareness of the importance of finish, and a shortage of suitable labour, has encouraged many firms to mechanise their electroplating and to adopt processes which reduce or eliminate hand polishing. The continuing research and development activities of the Udylite Corporation has also resulted in a flow of new products and processes becoming available, through the Electro-Chemical Engineering Company, to the European and Commonwealth markets. With a highly qualified staff of chemists, mechanical, electrical and chemical engineers, considerable and continuing progress has been possible in the design and manufacture of special equipment.

One example of a notable installation was the provision of two electro-galvanising lines for zinc plating steel sheets for John Summers & Co., Ltd. A third line has recently been completed. These machines are over 200 ft. long, and include cleaning, plating and phosphating cells through which steel sheets are continuously passed. It is of interest to note that throughout Western Europe and the British Commonwealth Efco-Udylite processes are already in use, in many cases in Efco-Udylite automatic machines.

The New Factory

The site has an area of 3 acres, the initial development being over a frontage of two-thirds of the site. It consists of six bays, each 35 ft. in width, five of these having a length of 66 ft. and a height to the underside of truss of 16 ft. The sixth has a length of 88 ft. and a height to the underside of truss of 23 ft., this bay, having a 3-ton overhead crane. Three bays are in use for chemical products and three for engineering. A building, 20 ft. in width, is connected to the main factory and runs the full width of the six bays (210 ft.): this contains the demonstration plating shop, analytical and development laboratories, and offices for chemists. To the north, is a separate office block with two floors, which is connected to the works by a covered way and provides accommodation for engineers, draughtsmen, purchasing and sales departments and administrative personnel.

The floor area of the factory is 21,000 sq. ft. and that of the office block, 7,000 sq. ft. It is planned to lay out the area adjacent to the office block as a garden, and to retain as many existing trees as possible.

Construction

The factory has a steel frame structure and the use of insulated decking for the roof, comprising insulation board sandwiched between sheet steel on the underside and roofing felt on the outside, has made it possible to design a truss more pleasing in appearance than the normal type, and to reduce the cubic capacity of the area which requires to be heated without affecting headroom. At the same time, excellent roof lighting has been provided.

The floor of the factory has been screeded and treated to give hardness and a dust-proof finish, and in those areas where acids are used, special acid-resisting asphalt floors have been laid.

The office block structure is of a pre-fabricated type, based on a 40 in. module which consists of a latticed steel skeleton clad with reinforced concrete slabs with textured and coloured outer faces and an inner breeze skin. An insulated flat roof and pre-fabricated plaster slab ceilings are incorporated.

Chemical Mixing

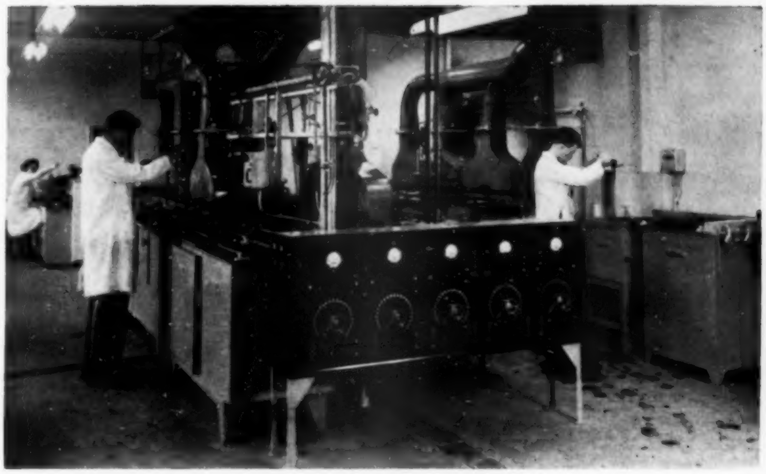
The chemical mixing platform has been designed so that raw materials are brought to it by fork-lift trucks and are added to the various mixing tanks after measuring. Raw materials are stored on pallets in the works,

Part of analytical laboratory.

and a store for finished products and space for export packing has been provided. After stirring, solutions are filtered, pumped to storage tanks and filled into carboys. A fume extraction system has been incorporated. Special corrosion-resistant materials have been used in view of the chemicals being handled. Many of the tanks and much of the pipework are rubber lined, others are in stainless steel with ducting made of plastic material.

Machine Shop

The small machine shop includes: a Mitchell $8\frac{1}{2}$ in. × 8 ft. sliding, surfacing and screwcutting lathe; a Mitchell $6\frac{1}{2}$ in. × 8 ft. sliding, surfacing and screwcutting lathe; a Selson horizontal plain milling machine; a Tangye 15 ton sleeving press; a Burdett slotting machine; a Doall 16 in. bandsaw; and various small bench and floor-mounted drills and grinders.



Demonstration plating shop

Demonstration Plating Shop

The demonstration plating shop equipment has been specially designed to enable a wide variety of electroplating processes to be used. There are eight separate services, namely, A.C. and D.C. electrics, hot and cold water, steam, gas, and low and medium pressure compressed air. Exhaust ducting is of rigid P.V.C. construction. The false ceiling is formed of Asbestolux slabs, and vapour-proofed fluorescent lighting has been provided. An effluent disposal plant is included to purify wastes from the chemical mixing plant and the demonstration plating shop.

Heating

The boiler house installation consists of two oil-fired boilers burning 200 sec. oil, one being a Davey-Paxman horizontal triple pass super-economic boiler with an output of 2,000,000 B.Th.U./hr. Provision has been made for the installation of a second horizontal boiler, in which event the vertical boiler will be repositioned and will continue to supply the summer load. Space heating in the works comprises suspended steam unit heaters. There is also a hot water/steam calorifier incorporated for heating the office block through radiators.

Further Extensions

The buildings have been laid out in such a manner that they can be readily extended without interruption of the existing processes, and, in fact, the present layout has been made in accordance with the ultimate requirements, when the factory will have been extended by at least 100%. Provision has also been made for the extension of the office block by 70%. Service roads have been laid out with the future extensions in view, and provide access to hard standings where drums and containers are stored externally. Separate access is provided to the office block and chemical and engineering parts of the works. The Consulting Engineers for the whole scheme were Campbell, Gifford & Morton, Ltd., Netherby, 161 Queens Road, Weybridge. T. A. Bird, A.R.I.B.A., was Consultant Architect for the office block.

The new Sheerwater Factory will undoubtedly permit an expansion in the already considerable activities of Electro-Chemical Engineering Co., Ltd. Since much of the Company's business is in the Midlands, a Depot has also recently been opened in Birmingham which permits stocks to be held and same-day deliveries to be made. This is in addition to the Sales Offices already existing in Birmingham, Manchester and Sheffield.

Protective Coatings for Molybdenum

Electroplated coatings of chromium and nickel are considered as among the most promising means for protecting molybdenum from oxidation under high-temperature conditions. Chromium, which is soluble in molybdenum in all proportions, forms no brittle intermetallic compounds with the latter. When used alone, however, chromium coatings tend to crack when heated. Nickel is of interest because it has very high ductility and relatively good resistance to oxidation by atmospheres containing molybdenum trioxide. Nickel, however, forms brittle intermetallic compounds with molybdenum.

Roger J. Runck of Battelle reports that he and his colleagues, by metallographic studies, found that in single layer coatings, chromium is less subject to bonding failure than nickel, and also gives better protection against oxidation. Their study for the Fansteel Metallurgical Corporation also showed that multiple-layer coatings of chromium and nickel, with the former at the interface, showed some superiority over single-layer coatings of either chromium or nickel. However, there is a tendency for blisters to form between the nickel and chromium layers.

Brightside Mill Order

The Brightside Foundry and Engineering Co., Ltd., have been successful in obtaining a contract from British Insulated Callender's Cables, Ltd., for a semi-continuous copper rod mill for their Prescot Works. The mill will embody many features of advanced design and mechanisation, and will have an output of some 50,000 lb. per hour of high quality copper rod.

Continuous Gas Carburising of Gears

New Installation at E.N.V. Engineering Company

THE E.N.V. Engineering Co., Ltd., was founded in 1910 to make an aero engine known in France as "Le Moteur en-V." Hence the original title of the Company—E.N.V. Motors. The manufacture of aero engines ceased during the 1914-18 war and the company has since specialised in gears, with particular emphasis on spiral bevel and hypoid gears, for which it is equipped with a modern plant which is probably the largest of its kind in Europe.

Current production embraces final drive gears and gearboxes for passenger and commercial vehicles, including complete differential assemblies for the well-known Eaton two-speed axle for commercial vehicles; gears and associated components for agricultural machines, aero-engines, flying controls, helicoptor rotor drives, locomotives and railcars; and large spiral bevel and hypoid gears up to some 72 in. diameter for heavy-duty industrial and marine drives.

Case-Hardened Gears

Case-hardening steels are necessary to provide the wear and strength qualities required for most types of transmission gears, hence the overwhelming majority of E.N.V. gears are of alloy steels, carburised and quenched after gear cutting. Gears which are too large for this treatment are flame-hardened by the latest Gleason machine.

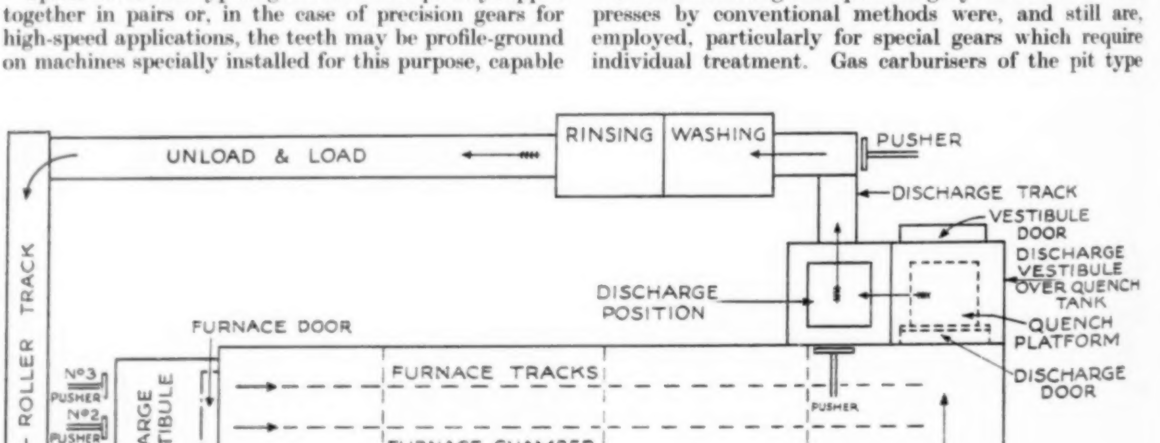
Spiral bevel and hypoid gears are subsequently lapped together in pairs or, in the case of precision gears for high-speed applications, the teeth may be profile-ground on machines specially installed for this purpose, capable of handling gears up to approximately 27 in. outside diameter. Spur gears up to this size are also furnished with profile-ground teeth when required.

With components as highly stressed as gears, heat treatment is a vital part of the manufacturing process. A very high standard of physical properties must be maintained, and distortion must be reduced to the minimum. Spiral bevel and hypoid gears and some types of cylindrical gears present special problems in this connection, because the gear teeth are developed to give localised contact and thus avoid load concentration at the tips and ends of the teeth in service. In case-hardening, some change of shape of gear teeth is inevitable. The heat treatment process takes place after costly machining operations on expensive material, and considerations of both quality of product and economics of production demand that every possible step be taken to control distortion and to ensure consistency, so that due allowance for movement of the teeth can be made during initial cutting.

To this end, the heat treatment process has been for many years under the supervision of a well-equipped laboratory, the staff of which have carried out considerable work on the problems associated with the quantity production of case-hardened gears.

Continuous Gas Carburising

Pack carburising and quenching by oil bath or under presses by conventional methods were, and still are, employed, particularly for special gears which require individual treatment. Gas carburisers of the pit type

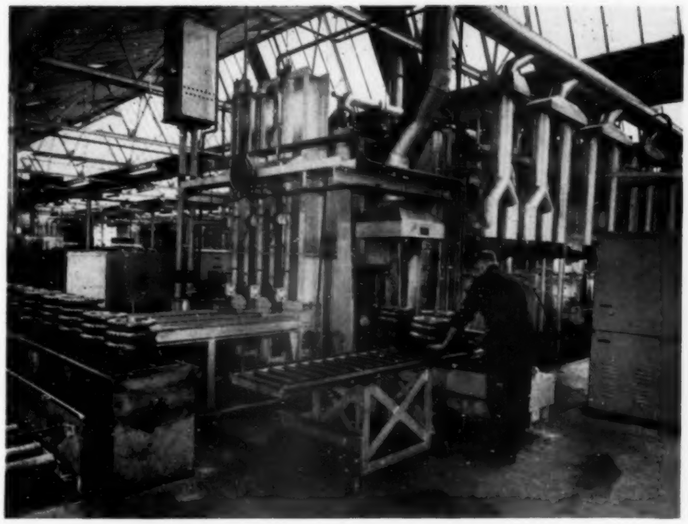


Layout of the furnace.

have been used for many years with such good results that it was decided to investigate the possibilities of continuous gas carburising, a development of the batch process, used increasingly in the U.S.A., where experience seemed to indicate that the continuous process was the most satisfactory treatment yet devised for the consistent production of gears. This consideration, added to economic advantages, influenced the decision to install a continuous gas carburising furnace, in the design of which the firm's metallurgists collaborated with the design team of Birlec, Ltd.

Care was taken to make the furnace as versatile as possible in operation, and at the same time to provide almost completely automatic control, so that the process would not be subject to human error and inconsistency.

Experience has shown that although carburising atmosphere gas can be satisfactorily prepared from town's gas, the composition of gas from the supply mains is liable to considerable variation. This would have produced difficulties in obtaining the degree of consistency which was the main objective of the new installation, and it was, therefore, decided to manufacture the furnace atmosphere from propane, and a storage plant for liquid propane has been installed for this purpose.



New work is mounted on special trays and fed into the vestibule with the conveyor shown.

The New Furnace

Having a rated output of 600 lb. of work per hour—which may be appreciably exceeded if only a medium case depth is required—the new furnace is capable of an output of something over 40 tons per week of 168 hours. The loading, carburising, quenching, washing and unloading of the work is all carried out within a floor space of approximately 49 ft. × 25 ft., the length of the furnace heating chamber being approximately 31 ft.

The material to be treated, comprising various automobile transmission gears, is loaded on heat resisting, grid-type trays 18 in. square. These trays are moved through the furnace on three parallel tracks, each tray carrying up to 150 lb. of gears. Special fixtures are provided for supporting gears of certain types, to enable the tray capacity to be used to the best advantage.

Heating is by means of gas-fired radiant tubes, arranged transversely above and below the conveyor tracks, and full furnace output is obtained with a gas consumption of the order of 4,200 cu. ft./hr. Carburising atmosphere is provided from Birlec Endothermic generators, one serving the furnace chamber proper, another the vestibules or lock chambers at each end, and a third being held as a stand-by. The atmosphere is formed from propane, which is supplied from two storage tanks, replenished in bulk from road tank wagons. The two generators in use at any one time require approximately 160 cu. ft./hr. of propane for an output of about 1,600 cu. ft./hr. of atmosphere gas to feed the furnace and a periodic on-off supply of 1,000 cu. ft./hr. for lock chamber purging.

Mechanisation

A high degree of mechanisation with automatic control incorporated in the work handling system enables the furnace to be run at full output with only two men. This applies when work is direct quenched from the furnace, but provision is made for the alternative extraction of individual work pieces by hand for press quenching, in which case another man is desirable to handle the gears from the furnace into the quenching presses. In both cases, the work carrier trays are circulated continuously through the furnace and along the discharge-reloading track, so that labour is confined solely to the removal of finished material and the reloading of the trays with fresh work. All work is cleaned in a washing machine before loading, and the operators handle both this and the tempering operation subsequent to case-hardening.

The complete cycle includes the following main operations. All movements are effected by hydraulic rams, energised by a central pump unit and controlled electrically through the sequencing circuit. A non-inflammable hydraulic fluid is used to obviate fire hazard from leaks.

Charging

This is normally carried out after every third cycle or push, i.e., when each track has moved once, and comprises the following stages :—

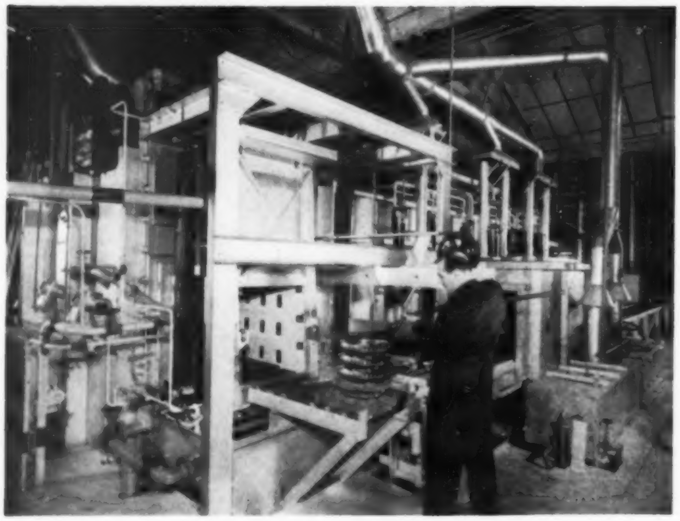
(1) Freshly loaded trays are moved by hand from roller track to transfer trolley.

(2) The entrance vestibule door is opened, the loading trolley extracted mechanically, and the trays moved onto it by hand. The loading trolley is then returned to the vestibule and the door closed.

Furnace Cycle

Each track has an individual timer which sounds a warning bell and gives a light indication at the set push intervals. The following automatic sequence is then started with one push-button.

(1) The inner charge door opens and the new tray on the given track is pushed from the vestibule into the furnace to move the whole track one tray



Discharge end of the furnace, showing the operator unloading crown wheels for transfer to quenching presses.

length forward. At the discharge end, the forward tray is lined up against a stop by an extractor mechanism.

(2) The quench elevator rises, the inner discharge door opens and the forward tray is pushed sideways into the discharge vestibule. The inner door closes.

(3) The quench elevator descends, immersing the tray of work in a fast moving vertical oil stream for a pre-set quenching time.

(4) The tray moves sideways in the quench tank and is elevated to the discharge position.

(5) The tray is pushed onto the discharge track and pushed through the washing machine to the unloading position. Unloaded trays continue along the track for reloading.

Press Quenching

When the work requires press quenching, a switch is operated at the discharge end. This interrupts the sequence when the tray is in the vestibule. A signal is given automatically, and the outer door can then be raised to extract the work. The tray is returned and the closing of the door sets the remainder of the cycle into automatic operation.

Purging

Every time an outer lock chamber door is opened, the atmosphere within burns away. Coincident with the door closing, the generator providing purge gas automatically comes into operation, and gas is fed for a preset time into the vestibule to sweep out the air and burnt gas.

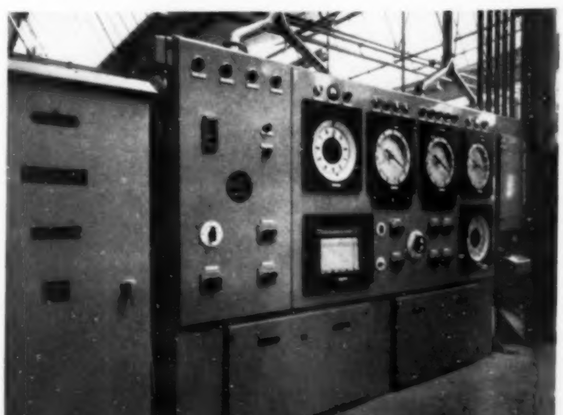
Metallurgical Control

As in any gas carburising furnace, the depth of case formed on the work can be regulated both by furnace temperature and by soaking time. The carbon content of the case is controlled independently by the composition of the atmosphere gas. The correct carburising temperature for given conditions, however, is generally higher than the optimum temperature for quenching, and provision is therefore made for controlling this temperature separately.

For this purpose, the furnace heating chamber is divided into four successive zones, or heating sections, each subject to independent, automatic temperature control. The first zone raises the temperature of the load to the predetermined value, while the second and third zones maintain this temperature for a period determined by the rate at which the trays are moved along the tracks. The second and third zones are equipped with gas-circulating fans to ensure uniform carburising over all surfaces of the work. In the final zone, the temperature of the load is reduced to a second predetermined level to give correct quenching conditions, and for this purpose the final zone is equipped for either heating or cooling, as required, by means of a three position temperature regulator.

A convenient means of assessing the carburising potential of the atmosphere gas is by measurement of its dew point, and a recording instrument is provided for this purpose, being arranged to operate either on the generator gas or on the furnace atmosphere, which comprises generator gas enriched with propane. To give a case of about 0·8% carbon content, a propane addition of about 1% of the atmosphere gas flow is needed, corresponding to a depression of dew point from 30°/40° C., as generated, to 10°/15° C. in the furnace.

A range of case depths between about 0·03 in. and 0·06 in. is obtained by variation in the cycle time. For practical purposes, a minimum track cycle time of about 27 minutes is used, corresponding to nine hours total time for each tray load in the furnace, and under these conditions an output as high as 800 lb./hr. is obtainable with a case depth of the order of 0·038 in. It is noteworthy that independent cycle timing devices are provided for each of the three furnace tracks, so that work may move at a different speed on each track, if required, to produce different case depths.



This view of the instrument panel shows the recording and controlling instruments which provide automatic temperature control for the various zones. The sequencing control gear is behind the panel on the left.

Conclusion

Designed for a clearly specified range of duties, this new furnace installation is admirably adapted to the flow-line requirements of a plant engaged on the large-scale production of automobile gears. It makes possible the elimination of a separate reheating operation after carburising and eliminates much manual handling. This results in great economy in both labour and floor space, as well as in respect of fuel consumption.

The installation has now been in use for several months and the fact that but few teething troubles of only a minor character were experienced, is a tribute to the extensive investigations which were carried out and to the thoroughness of the design.

Throughput is currently of the order of 30 tons per week and the reduced distortion of pieces coupled with the consistently high standard of physical properties have amply justified expectations.

Anti-Vibration Levelling Mounts for Machine Tools

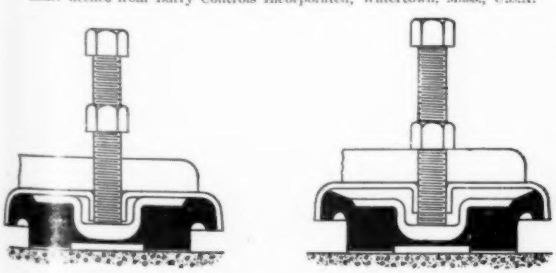
MANY engineers and factory managers are faced with the problem of mounting machine tools on vibration isolators, either to avoid transmission of vibration to nearby machinery or sensitive equipment, or to ensure that the precision of the machine tool itself will not be upset by its own vibration. Here it should be emphasised that it is quite permissible for a machine tool to move upon its resilient mounting, so long as it moves as a complete unit. Very precise measurements have proved that a precision grinder, for example, can move in such a manner without in any way damaging work in progress, provided it rests upon a firm foundation.

The Barrymount levelling machine mount* is a particularly effective method of isolating vibration. It has another important feature : machine tools no longer have to be bolted by foundation bolts which are grouted into the concrete floor. The two sketches (Fig. 1) show this isolator below the base of the machine tool ; on the left the attaching bolt is bottomed, and on the right the bolt has been turned down until the machine has been levelled precisely, and the lock nut has been tightened.

With this simple and robust isolator, machine tools of any size and type can be set and installed in a few minutes, in striking contrast to the hours of work needed to cut holes in concrete for foundation bolts, to locate them in position with the aid of a template, and to fix them with cement grout which must be given time to set. Moreover, machines can be placed exactly where they are required, and their setting is not affected by underground pipes, steel reinforcement, cables, or any other obstacle to foundation bolts.

Experience has amply proved that this isolator greatly reduces the noise from punch-press plant, and from heavy, high-speed equipment, as a result of which working conditions are improved in adjacent drawing-offices, laboratories and administrative buildings. In addition, precision machinery is isolated from external shock which may cause irregular surface finish. Sensitive machinery and electronic equipment may be located where best required for flow of work, without being affected by the presence of other machines.

* Made by Cementation (Muffelite), Ltd., 29 Victoria Street, London, S.W.1, under licence from Barry Controls Incorporated, Watertown, Mass., U.S.A.



(a) (b)

Fig. 1.—(a) Mount beneath bed of machine, with attaching bolt bottomed, before levelling ; (b) the bolt has been turned down until the machine is levelled precisely, and the lock-nut tightened. Rubber is shown in black.

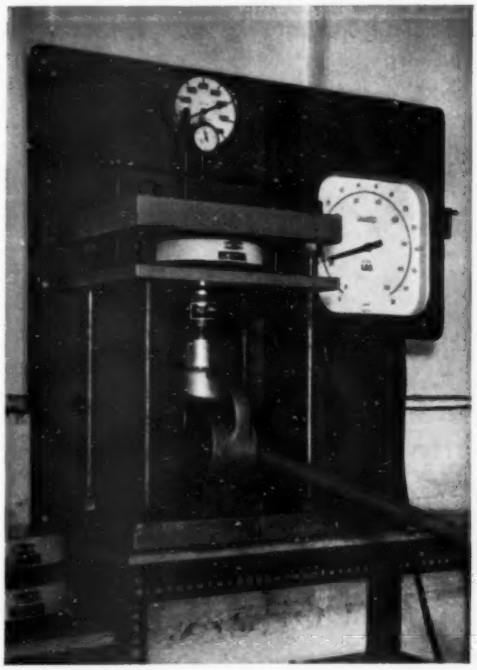


Fig. 2.—Apparatus for testing Barrymount levelling machine mounts.

Testing Facilities

The laboratory of Cementation (Muffelite), Ltd., is well equipped for testing the range of machine tool isolators manufactured. A simple apparatus (Fig. 2) has been designed and made in the laboratory for testing the load-bearing characteristics of these. Load is applied by a Tangye hydraulic jack of simple yet rugged type, and the load is measured by means of an Elliott load cell, which has been aptly described as the most convenient modern method available for weighing a load electrically, eliminating knife edges, springs and all other moving parts in the weighing mechanism. A Budenberg gauge reading up to 3,000 lb./sq. in. is fitted to the

hydraulic circuit of the jack, to provide a check of load readings obtained electrically.

An isolator is set up in this apparatus, and static deflexion is measured for increasing increments of load by the simple dial gauge, a precise measurement being provided by an Elliott load cell ; a curve is then plotted showing static deflexion against load. From this curve the variation of static stiffness with load is determined.

Owing to the limited capacity of vibration test equipment, it has not been possible to determine the dynamic stiffness characteristics of the larger sizes of industrial isolators. A vibration test has been carried out on the smallest industrial isolator to relate load with natural frequency. From this test, it has been possible to calculate dynamic stiffness of the isolator, and hence the relationship between dynamic and static stiffness ; using this relationship in conjunction with the results of static tests, it has been possible to calculate the dynamic characteristics of the larger industrial isolators. Experience has proved that the accuracy attained is well within the required tolerances.

The testing apparatus is simply an hydraulic compression testing machine, in which load is applied by a Tangye hydraulic jack with a maximum capacity of 15 tons, the load being measured by an Elliott load cell placed between the ram of the jack and the moving platen. Two alternative load cells may be used, one covering the range from zero to 3,000 lb. the other from zero to 18,000 lb. both of which can be connected to the Elliott self-balancing bridge unit. In order to eliminate errors in readings of deflexion, arising from non-axial loading of the isolator under test, the dial gauge is mounted directly above the ram so that average deflexion will be measured.

Novel Mine Air Conditioning System

A UNIQUE system that raises the temperature of cold air in the winter by making ice and uses the ice to reduce the temperature in the summer has been put into service at the Stobie section of the International Nickel Company's Frood-Stobie Mine in the Sudbury District of Ontario. Instead of stoking the furnace or turning on the oil burner when the thermometer dives below zero during Northern Ontario's frigid winters, ice production is stepped up to take the chill off the fresh air supplied from the surface to the mine workings. Basis of this unusual system is the convenient twist of nature whereby heat is released when ice is formed.

Outsize Fan

The fan that delivers the air to underground has a diameter of 198 in., and is one of the largest in the world. This powerful fan, which has a top capacity of 750,000 cu. ft./min., blows fresh air from the surface through a 300-ft. vertical airway, 20 ft. in diameter, into two huge open stopes mined by the blasthole method for this purpose between the 300 and 500 ft. elevations. Each stope is 80 ft. wide, 200 ft. long and 200 ft. high, and the stopes are separated by a pillar 70 ft wide. The air circulates through the two stopes in succession on its way to the main intake.

Water from the mine's main pumping system is furnished at 120 lb. pressure to the four spray points at the top of each stope. The volume of water required in winter months varies up to 200 gal./min. The fine particles of water sprayed into the air passing through the stopes turn to ice, and the heat given up in the process is transferred to the air. Some 40,000 tons of ice were formed at the bottom of the stopes during the past winter. This heat, along with that absorbed by the air from the large area of wall rock exposed in the stopes, added up to 15,000,000,000 B. Th. U., or the equivalent of burning 100,000 gal. of oil or 850 tons of coal.

Although the surface temperature during the winter ranged to 25° below zero, the fresh air delivered from the main intake of the mine ventilation system 600 ft. below surface varied only between 27 and 30° above zero as a result of its side trip through the ice stopes. The temperature eventually is expected to be held at about 32° above zero as the system is improved.

140,000 Tons of Ice

When the volume of air handled through the system ultimately reaches full capacity of 750,000 cu. ft./min. as compared to 150,000–300,000 cu. ft./min., during the past winter, upwards of 140,000 tons of ice will be formed in the stopes during each winter. In the summer the ice will be melted as the warm fresh air passes through the stopes, and the air will be cooled between 5 and 10°. The humidity of the air will also be reduced as it cools below the dew point, and much of its moisture drops in the stopes. This phase of the Stobie air conditioning is similar to that at Inco's Creighton Mine, where fresh air being delivered to the mine is cooled by passing if through the natural refrigeration system in the old workings, where seepage water freezes during the winter.

At other Inco mines where heating of fresh air is required during the winter, steam or oil installations are used. When the Stobie operation was being planned and it was noted that the logical position for the main fresh air intake lay near a low-grade section of the orebody conveniently located between the two main mining areas, the feasibility of establishing ice stopes presented itself. As a result, Stobie has been equipped with a remarkably efficient air conditioning system at a fraction of the cost of a surface heating plant.

Bigger Queen Anne Furnace

AFTER completion of relining, the Queen Anne blast furnace at the works of Appleby-Frodingham Steel Co., Scunthorpe, a branch of The United Steel Co., Ltd., has a hearth diameter of 31 ft.—larger than that of any other known blast furnace. Queen Anne, one of Appleby-Frodingham's famous four " Iron Queens," was commissioned in March, 1954, when her hearth diameter was 27 ft., bosh diameter 30 ft. 3 in., throat diameter 22 ft., and height 100 ft., giving a working volume of 42,372 cu. ft. When she returns to service with the enlarged hearth, the bosh diameter will be 34 ft. 3 in., throat diameter 23 ft. 9 in., and height 100 ft., the effective volume being 51,615 cu. ft. During her first campaign, Queen Anne produced 800,000 tons of iron.

The Effect of Impurities on the Properties of Pure Iron*

In an attempt to assess the effect of small amounts of impurities on the properties of iron and steel, an investigation has been made using very high purity iron, with and without the addition of known amounts of various impurities, particularly carbon and nitrogen.

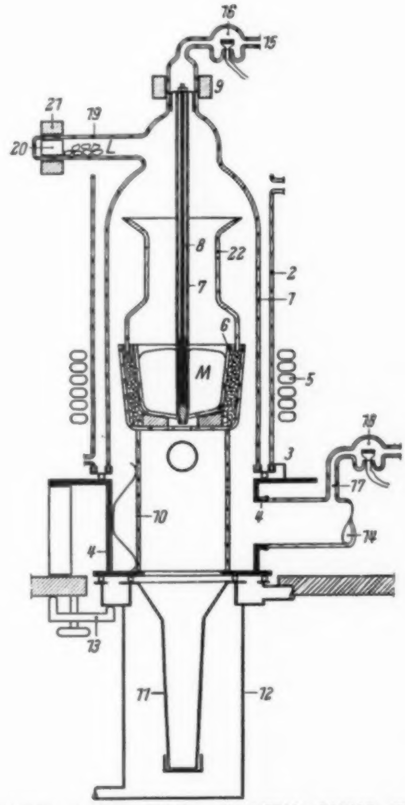
THE study of the properties of steels is complicated by the presence, even in unalloyed steels, of small amounts of impurities such as manganese, carbon, sulphur, phosphorus, oxygen, nitrogen and hydrogen. The use of commercial steels for testing has led to much controversy on the causes of such undesirable phenomena as ageing. To clarify the position, very high purity iron has been prepared, together with samples containing known small amounts of various impurities.

Preparation of Pure and "Impure" Iron

Up to 2 kg. of carbonyl iron is melted by high-frequency induction heating in an all glass apparatus under vacuums down to 10^{-5} mm. Hg pressure. In earlier work[1] the metal was allowed to solidify in the crucible, but recent modifications enable the metal to be cast into a mould directly after melting,[2] while still under vacuum. In this way, blowholes are eliminated and no machining of the specimen is needed. The apparatus is shown in Fig. 1. Casting is effected by magnetically raising the tube (7) so that the metal flows down into a slightly tapering copper mould (11). The quantity of metal is related to the mould capacity, so that any shrinkage cavities are confined to the upper conical part of the mould.

Commercial carbonyl iron in the form of sintered rods is treated with a calculated amount of oxygen and, when liquid, oxygen-free hydrogen is passed over it for several hours. When oxygen ceases to be evolved (as indicated by the appearance of an 18 : 8 stainless steel strip (18) in the exit gas stream[3]) the total content of carbon, oxygen and nitrogen is considered to be below 0·001%. The hydrogen still in solution is removed by evacuating to 10^{-3} mm. Hg, this operation being carried out gradually at first, to avoid excessive agitation of the melt.

Non-volatile alloying elements such as nickel or molybdenum may be added to the original melt. Elements of high oxygen affinity, e.g., manganese, chromium, aluminium, zirconium, titanium and vanadium, which might form oxides difficult to reduce by hydrogen, are added via the tube (19) (Fig. 1). When adding manganese, which is relatively volatile, the hydrogen is displaced by argon to obviate the need for evacuation. Zirconium and titanium react with hydrogen and must be added after its removal. Gaseous oxygen is readily taken up by pure molten iron but, due to the high partial pressure of nitrogen above nitrogen-containing melts, only small nitrogen contents can be obtained in this way. Higher quantities of nitrogen may be introduced by conventional nitriding methods.



1. BELL-SHAPED HARD GLASS VESSEL
2. GLASS MANTLE ENCLOSING SPACE FOR COOLING WATER
3. METAL RING FOR VACUUM SEAL
4. SUPPORT FOR FUSION VESSEL
5. HIGH FREQUENCY COIL
6. CRUCIBLE
7. STOPPER FOR CRUCIBLE
8. MOLYBDENUM ROD
9. COIL FOR STOPPER ROD
10. SILICA SUPPORT FOR CRUCIBLE
11. MOULD
12. METAL CASING (SPACE FOR COOLING WATER)
13. THREE CLAMPS SECURING 12 TO 4
14. CONNECTION TO PUMP
15. GAS INLET
16. OXYGEN INDICATOR
17. TUBE TO BACKING PUMP
18. OXYGEN INDICATOR
19. TUBE FOR NON-VOLATILE ADDITIONS
20. MOVABLE MAGNETIC MASS
21. MAGNETIC COIL
22. SILICA GLASS CHIMNEY

Fig. 1—Apparatus for melting under vacuum.

Effect of Crucible Composition

The value of the equilibrium constant $K = [Al]^2\ [O]^3$ for the reaction $Al_2O_3 = 2\ [Al] + 3\ [O]$ is such that at low oxygen contents the iron tends to pick up aluminium from alumina crucibles. A comparison of analyses of irons melted in alumina and magnesia crucibles shows the latter to be superior, due to the negative heat of solution of magnesium in iron.

Examination of the Prepared Alloys

Quench Ageing

To study the effect on quench ageing of carbon, nitrogen and oxygen, samples were prepared[4] of pure

* An abridged translation of a paper by J. D. Fast published in *Stahl u. Eisen*, **73**, 1484–96.

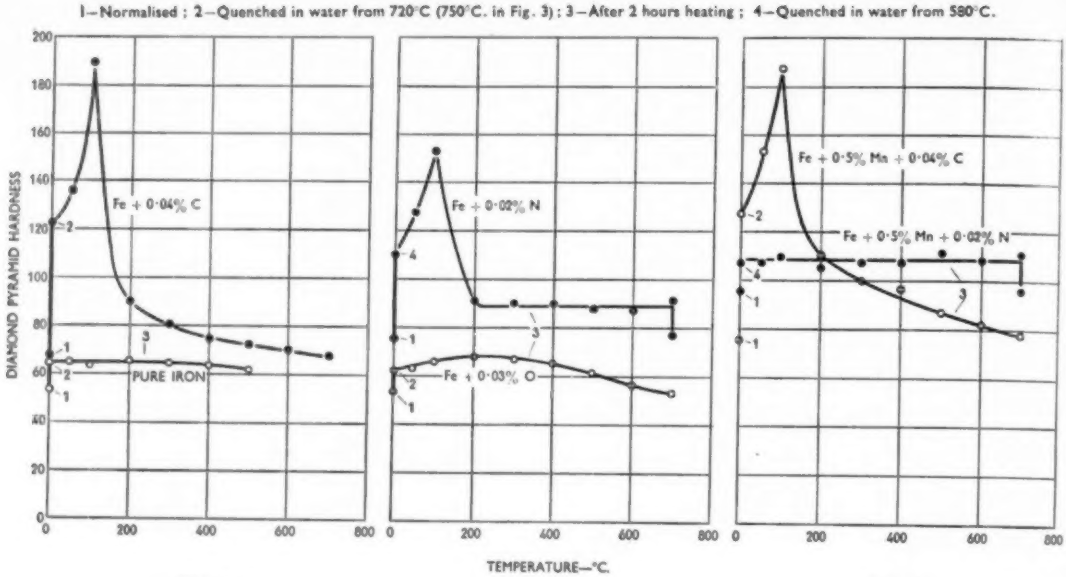


Fig. 2. Fig. 3. Fig. 4.

Fig. 2–4.—Effect of carbon, oxygen, nitrogen and manganese additions on the hardness of pure iron after heat treatment.

iron and irons containing 0·03% oxygen, 0·02% nitrogen and 0·04% carbon, respectively. Additions of 0·5% manganese were made to some of the iron samples containing nitrogen and carbon. The results, showing the variation of hardness with temperature after normalizing and water quenching of the samples, are given in Figs. 2–4.

As might be expected, pure iron shows no quench ageing effects, which are clearly due to the presence of carbon and nitrogen. The slight effect of oxygen suggests, either that it is less soluble in α-iron or that, unlike carbon and nitrogen, it enters into substitutional solid solution with α-iron. Figs. 3 and 4 demonstrate the important fact that 0·5% manganese practically inhibits precipitation in nitrogen-containing iron, but has no effect on carbon irons.

From measurements of damping capacity[5, 6], dealt with in more detail later in the paper, it may be deduced that nitrogen atoms are situated preferentially in those interstitial positions adjacent to manganese atoms, this being the configuration of lowest energy. Nitride precipitation is thereby impeded, since the nitrogen must first escape from the manganese atoms. This explains why precipitation is much more rapid in pure irons than

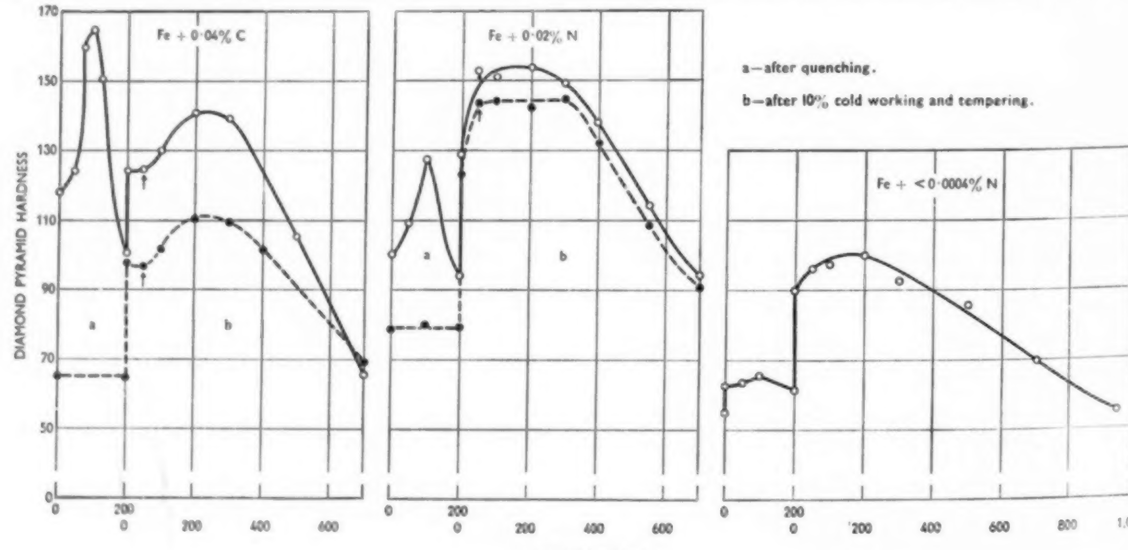


Fig. 5. Fig. 6. Fig. 7.

Fig. 5–7.—Effects of small additions of carbon and nitrogen on the hardness of pure iron after thermal and mechanical treatment.

in commercial irons, which always contain manganese.

Even after relatively slow cooling, some of the phenomena associated with quench ageing may manifest themselves. An example of this is the "magnetic" ageing of mild steels studied by W. Koster, who found that with a nitrogen content of 0·005% the coercive force increased to twice its original value on heating for several hundred hours at 100° C. It may be concluded from damping capacity and ageing tests that this "magnetic" ageing is due to the combined presence of manganese and nitrogen in the steel. Manganese has an affinity for nitrogen greater than that of iron, but not sufficient to bind the nitrogen permanently in the lattice. This may, however, be achieved by the addition of elements of stronger affinity for nitrogen, such as aluminium, zirconium, titanium, vanadium or niobium.[7]

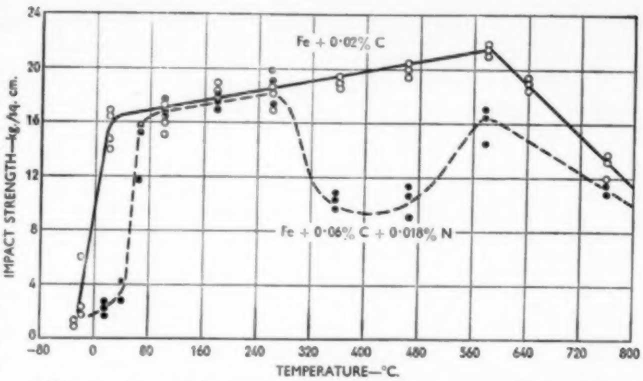


Fig. 8.—Impact-temperature curves for iron containing 0·02% carbon, and 0·06% carbon with 0·018% nitrogen.

Strain Ageing

A series of alloys of known composition has been prepared as described above[4, 8] to investigate the effects of impurities on strain ageing. The results are given in Figs. 5–7. The dashed curves represent hardness values after normalizing, 10% cold deformation and 2 hours annealing at temperatures of 50° C., 100° C., etc. The continuous curves show first the quench ageing effect and then, after 2 hours annealing at 200° C. and 10% cold deformation, the effect of strain ageing. The figures show the different behaviour of carbon and nitrogen, and suggest that the latter element is the main cause of strain ageing. This is supported by the knowledge that strain ageing is slight in commercial steels to which aluminium has been added. The effect of strain ageing on the structure of iron alloys has been studied by A. H. Cottrell[9] and is discussed later. Oxygen was found to have no effect on ageing properties.

Blue Brittleness

A comparison of the tensile strengths and ductilities of samples containing 0·02% nitrogen or 0·04% carbon with those of pure iron shows that blue brittleness is dependent on the nitrogen content of the steel.[10] The minimum occurring between 400° and 500° C. in the curve of notched impact strength against temperature is often put forward as the cause of blue brittleness. As is shown in Fig. 8, the author has found[11] that this minimum is absent when the steel contains carbon alone, and only appears in the presence of nitrogen.

Effect of Oxygen

Impact tests[11] show that the presence of more than 0·01% oxygen in iron is sufficient to cause brittleness. Microstructural examination reveals that, in oxygen-containing irons, failure at low temperatures is intercrystalline, indicating that oxygen causes weakening of the grain boundaries. These findings are confirmed by the N.P.L. at Teddington[12] in work on the same phenomenon.

Carbon, even at the grain boundaries, has no such weakening effect. This may be due to the fact that, whereas oxygen forms a submicroscopic film, carbon is present at the grain boundaries in the form of carbides. C. S. Smith[13] considers the difference in behaviour to be related to the surface tensional differences at oxide/iron and carbide/iron interfaces. It is of great importance that traces of carbon (0·002%) are sufficient to counteract the undesirable effect of 0·01–0·1% of oxygen, as shown by the curves of notched impact strength at 20° C. as a function of oxygen content (Fig. 9). This effect of carbon may be attributed to changes in surface tension causing the FeO to coagulate at the grain boundaries.

General Considerations of the Effect of Carbon and Nitrogen in Steel

Role of Energy of Deformation

When a foreign atom is dissolved in the iron lattice, the latter undergoes a distortion proportional to the radius of the atom introduced. For qualitative purposes, the heat of solution may be considered as the sum of the elastic energy of deformation, which is always positive, and a reciprocal energy effect whose sign depends on the various atoms involved.

If it is assumed that, in the introduction of carbon and nitrogen into the iron lattice, the deformation energy is of greater importance than the reciprocal energy effect, it is then possible to trace a connection between several phenomena hitherto apparently unrelated. It will now be shown that Snoek damping and strain ageing are both connected with the greater solubility of carbon and nitrogen in austenite than in ferrite, and with the formation of martensite.

Solubility of Foreign Atoms in Austenite and Ferrite

Regarding iron atoms as spheres, they occupy 74% of the total volume in the face-centred-cubic austenite lattice. The remaining 26% of space consists of: (*a*)

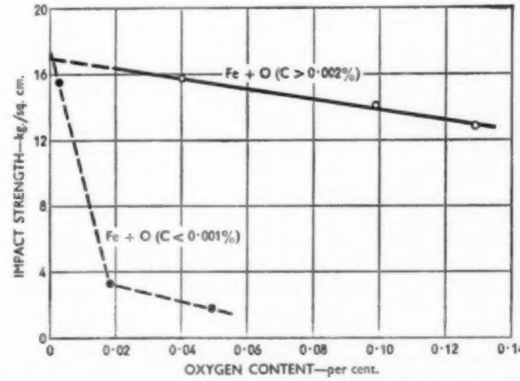


Fig. 9.—Effect of oxygen on the impact values of iron at 20° C.

octahedral holes surrounded symmetrically by six iron atoms; and (*b*) tetrahedral holes surrounded by four iron atoms at the corners of a regular tetrahedron. The sizes of these holes, expressed as the largest sphere which may be accommodated without distortion, are :—

$$r_{\gamma}^{6} = 0 \cdot 41\ R \qquad (1)$$

$$r_{\gamma}^{4} = 0 \cdot 23\ R \qquad (2)$$

where R is the radius of the iron atom. For the body-centred-cubic lattice of ferrite, the vacant sites are 32%, again divisible between two types of hole of co-ordinations 6 and 4 whose sizes are $r_{\alpha}^{6} = 0 \cdot 155\ R$ and $r_{\alpha}^{4} = 0 \cdot 29\ R$. Although the total free space is greater in the body-centred-cubic lattice, this is due rather to the number than to the size of the holes. Thus, there are 3 (α, 6) and 6 (α, 4) holes per iron atom in the α-lattice, and only 1 (γ, 6) and 2 (γ, 4) holes per iron atom in the γ-lattice.

Since the radii of carbon and nitrogen atoms are, respectively, 0·62 R and 0·56 R, their introduction into the lattice causes distortion, which is greatest in α-iron. In agreement with the difference in diameters, the solubility of nitrogen at the eutectoid temperature is 0·1% by weight in α- and 2·3% in γ-iron, while that of carbon is only 0·02% in α- and 0·8% in γ-iron. Comparison of solubilities is only possible in this case because of the low stabilities of the carbide and nitride phases ; the low solubility of oxygen in iron is certainly due to the greater stability of the oxide. In both α- and γ-iron, the atoms of carbon and nitrogen occupy the octahedral holes.[14]

Snoek Damping Capacity

At equilibrium, carbon and nitrogen atoms produce tetragonal distortion of the α-iron lattice and, although mobile, they maintain a uniform distribution, so that the lattice is equally distorted in all three dimensions. If a stress is now applied in one direction, it produces more space along the axis of stress and less in the remaining directions, due to the Poisson contraction. As a consequence of this, the dissolved atoms occupy these larger holes to a greater extent, and a new equilibrium is attained, having the minimum free energy for the given temperature. The establishment of this equilibrium by diffusion occupies a finite time, and under load a phase change will normally occur with a decrease in free energy.[6] The damping of free oscillations within the metal will be greater the greater the phase change angle β, given by

$$\beta = \triangle \frac{\omega\tau}{1 + \omega^2\tau^2} \qquad (3)$$

where ω is the frequency of mechanical oscillation, and τ the relaxation time corresponding to the time spent by carbon or nitrogen atoms in intermediate lattice positions, given by

$$\tau = \tau_0\, e^{\,U/RT} \qquad (4)$$

(U is the activation energy for diffusion of the dissolved atoms). $\triangle$ is termed the relaxation force and is, according to D. Polder[15] and L. J. Dijkstra,[16] proportional to the concentration of carbon or nitrogen atoms. From (3), damping capacity will be at a maximum when $\omega\tau = 1$. The measurement of damping has been applied to the study of diffusion, solubilities, precipitation and the effects of impurities. The effect of 0·5% manganese on the precipitation of nitrogen in steel has been determined in this way.

Martensite Formation

Because of the local distortion of the α-iron lattice when one carbon or nitrogen atom is introduced, less energy is required for the introduction of successive atoms,[17] and the formation of a relatively stable supersaturated solution is possible where the atoms only occupy the holes in one direction, as occurs when γ-iron relatively high in carbon or nitrogen is quenched—a tetragonal lattice structure termed martensite is produced in which there is little or no movement of the dissolved atoms.

Strain Ageing

This effect is attributed to the combined influence of dislocations and dissolved carbon or nitrogen atoms. As previously mentioned, dissolved atoms diffuse into those regions under greatest stress when they occupy positions of lower free energy. According to Cottrell and Bilby,[18] a " precipitate " of foreign atoms is thereby formed at temperatures below 400° C., consisting of one carbon or nitrogen atom per layer of iron atoms. When a dislocation separates from such a one-dimensional precipitate of foreign atoms, the metal is placed in a state of higher energy, as the interstices are now of normal size.

In the normal tensile test, an upper yield point is observed because rapid deformation assists the loosening of dislocations and, after separation, the movement of dislocations requires less strain. Immediately after deformation the dislocations are free, and strain ageing only occurs by the diffusion of carbon or nitrogen atoms towards these dislocations, where they are fixed with a consequent increase in hardness.

On the basis of the author's work in 1949,[19] a modification of the Cottrell theory of strain ageing is proposed. At room temperature, carbon will not cause strain ageing, a fact attributed by Cottrell to the lower solubility of carbon in relation to nitrogen. Dijkstra[20] has shown, however, that an increase in temperature from 20°–100° C. only raises the solubility of carbon (with carbide as the second phase) from about 10^{-7} to 5×10^{-6}%. This would still be insufficient to fix dislocations after a cold deformation of 10%, but, in fact, the material shows quite rapid strain ageing at 100° C. The fixing of dislocations must, therefore, be due to carbon supplied by carbide particles, which indicates that the energy of a carbon atom entering a dislocation is approximately equal to its energy when bound as carbide.

Work by Dijkstra[20] supports a similar mechanism for nitrogen. If we assume that the distances between dislocations and precipitated crystals are similar in irons containing carbon and nitrogen, and that the rate of strain ageing is determined by diffusion, then the different behaviour of carbon and nitrogen atoms (Figs. 5 and 6) is primarily due to the difference in the values of $D_C q_C$ and $D_N q_N$, i.e., the products of the diffusion coefficient D and the solubility in α-iron.[21]

The best values for the diffusion coefficients of carbon and nitrogen in α-iron are given by

$$D_C = 0 \cdot 02 e^{-20,100/RT}\ \text{cm.}^2/\text{sec.} \qquad (5)$$

$$D_N = 0 \cdot 007 e^{-18,000/RT}\ \text{cm.}^2/\text{sec.} \qquad (6)$$

The formula for D_C is derived from damping measurements by Wert[22] and classical diffusion measurements by Stanley[23] ; that for D_N is based on both kinds of measurements made by the author.[24]

The solubilities of carbon and nitrogen in α-iron are less well established. Measurements by Dijkstra,[20] Stanley,[23] and Wert[25] yield the equation

$$q_C = 2{\cdot}55e^{-9,700/RT} \text{ wt\%} \quad (Fe_3C \text{ as second phase}) \qquad (7)$$

while the calorimetric data of Borelius and Berglund[26] give,

$$q_C = 5{\cdot}8e^{-12,500/RT} \text{ \%wt.} \qquad (8)$$

The most reliable value for nitrogen in α-iron with Fe_4N as the second phase is probably that given by Borelius, Berglund and Avsan.[27]

$$q_N = 2{\cdot}33e^{-5,330/RT} \text{ wt\%.} \qquad (9)$$

From equations (6) and (9), the product Dq for nitrogen in α-iron at 50° C. = $1{\cdot}0 \times 10^{-18}$cm.^{2}/sec. From equations (5) and (7), Dq for carbon attains this value at 120° C., and from (5) and (8) at 145° C. In comparison with the experimental values in Figs. 5 and 6, agreement is quite good, especially if one assumes with Jack[28] that the nitride is present as the metastable form, $Fe_{16}N_2$.

It appears that at 50° C. nitrogen-containing solutions are super-saturated, while those of carbon are not. Thus, experimental and theoretical considerations support the view that the different behaviour of carbon and nitrogen in relation to strain ageing is mainly due to differences in the value of the product of diffusion coefficient and solubility in α-iron.

Other Phenomena

Since the "local" solubility of carbon or nitrogen depends on the local lattice pattern and energy of deformation, the tendency towards strain ageing may be diminished by alloying additions which reduce the value of the lattice constant, for example, in silicon steels used for electrical purposes.

The observed[29] preference of carbon and nitrogen atoms for grain boundary sites, where the lattice spacing is greater, confirms the role ascribed to deformation energy.

Carbon and nitrogen may also affect the properties of magnetostriction and polygonisation, and research on this subject is now in progress.

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Properties of Rhenium

THE metal rhenium, the uses of which are becoming better known as a result of recent studies, is coming into commercial production. Because the supply will be limited to a maximum up to 10 tons per year, rhenium prices are likely to range close to those for platinum. As it becomes available, rhenium is likely to go first into electrical and electronic applications, where minute quantities will give special high-performance characteristics. These views were expressed by Battelle metallurgists, C. T. Sims and R. I. Jaffee, in a paper given before the Metals Conference of the American Institute of Mining and Metallurgical Engineers in Buffalo, New York.

The solid metal is currently prepared by a process in which potassium perrhenate is converted in several chemical steps to high-purity rhenium metal powder, which is then compacted and sintered into a bar. Pressing and sintering operations are similar to those used to prepare tungsten and molybdenum.

Although the sintering procedure for rhenium is similar to that for tungsten, the similarity does not carry over to fabricating. The Battelle metallurgists pointed out that rhenium cannot be hot worked in air, because of inherent hot shortness. Research at Battelle, however, indicates that cold working can be accomplished by lightly working surfaces of rhenium bars to form a layer of dense, strong metal that prevents initiation of edge cracking. Following this, reduction by cold swaging and flat- or shape-rolling can be conducted. Because the metal work-hardens readily, annealing is required after each 1–2% reduction, for the first 10% total reduction. Subsequently, annealing is needed less frequently. Rhenium's rate and capacity for work-hardening also make it extremely difficult to machine, and metal-removing-type operations have been carried out primarily by grinding.

Sims and Jaffee described several present and potential applications of rhenium in their paper. These include uses as electrical contact material, in thermocouples, and as filament material for electronic tubes. Based on its wear resistance, rhenium might also serve as a material for penpoints, gramophone needles, and pivot bearings.

Lectures for Roll Turners

THE Rotherham College of Technology has recently been presenting a series of lectures specially arranged to meet the interests of roll turners. It is believed that this is the first occasion on which a College has arranged to provide facilities for those engaged in this branch of the industry. The lectures were given by specialists and were repeated fortnightly for the benefit of shift-workers. Introductory topics included steel making and rolling mill plant, whilst the main themes were roll-turning lathes and tools, problems met in roll-turning, roll-pass design and rolling problems. An attendance of more than eighty indicated the interest shown, and it is intended to follow this with further series of lectures on roll pass design during the 1956/57 session.

Starting Up a Steel Foundry in 1890

Some Unpublished History

By Eric N. Simons

When the firm of Edgar Allen & Co., Ltd., was formed in 1890, steel for castings was normally melted by the open hearth process or the crucible process. In this article, the author presents the early history of the firm's steel foundry with particular reference to the negotiations leading up to the adoption of the Robert process.

STARTING up a completely new steel foundry was in 1890 a much more hazardous and troublesome process than it would be today. In that year, on January 1st, to be precise, the firm of Edgar Allen & Co., Ltd., a private limited company formed by William Edgar Allen, who had been operating as a merchant and manufacturer since 1868 on his own account, under the title of Edgar Allen & Co., came into existence. Land had been bought from Earl Fitzwilliam at Tinsley, Sheffield, the site of an old wagon works, and it was proposed by the two new managing directors who joined Allen—Robert Woodward and Alfred Ernest Wells—to establish a foundry for the organized manufacture of steel castings.

In those days the melting of steel for casting into parts for machinery and plant was carried out by either the open-hearth process or the crucible process. It was felt by the newcomers that improved casting processes specifically suited to the production of steel castings ought to be available, and, in fact, they had seen in France such castings produced by a process known as the Robert process, which appeared to them to have undoubted advantages for their purpose. They began negotiations with G. Ellison Collette of the Robert Steel & Iron Co., Ltd., London, with a view to taking a licence for making steel by the Robert process.

Quoting from the very first letter on the subject, we record the opinion of one of the senior members of the firm, Robert Woodward, that " the adoption of the Robert process involves the great disadvantage of being able to use up only part of the runners, heads and waster castings—large pieces would have to be disposed of at a loss. The firm accordingly offers a royalty of 2s. a ton on marketable ingots, 1s. 6d. a ton on wheel centres for locomotion, and 2s. 6d. on all other castings." The Robert Company had suggested a flat rate of 10s. a ton. Some hectic haggling now took place: Woodward declared, " You will make a great mistake if you base any calculations as to the cost of castings on M. Robert's figures of £6 and only 9% waste." The waste figure, the Sheffield firm claimed, should be nearer to 12%, and £6 a ton would not " cover the cost of making the cheapest castings in this country."

Pursuing the correspondence, Woodward said: " With us it is a question of Robert *v.* open hearth and not Robert *v.* crucible melting. The Robert will not supercede (*sic*) crucible melting, and it is clear that we shall not be able to use up large runners and wasters, but shall have to sell them at a loss, i.e., under pig iron price. We considered the question of royalty based on selling prices and decided against it. Price is not an index of profit. Perhaps we may add (to show you how other inventors sometimes act) that a well-known firm in the town have the use of W. Siemens' latest gas pot-melting furnace without royalty because they were the first to adopt it and to make it a success—not without considerable trouble and expense. Even now, the royalty for that kind of furnace is only nominal."

On June 24th, 1890, Woodward wrote to Horace Sandars, 6, Great George Street, Westminster: " We have seen the process in operation in France and are prepared to put down a trial plant at our cost and risk; and as no-one in this country has adopted it yet (we are aware of the two provisional licensees) we have thought you would think it worth your while to make exceptional terms with a firm who would be likely to go into the thing with a view to making it a success."

An Improvement on the Bessemer Process

It ought to be mentioned here that the Robert process was basically an improvement on the Bessemer process, the blast being from the side and along the surface of the steel instead of up through the bottom.

Woodward met Kennard of the Robert Company in London on July 2nd and, returning home, wrote on the 4th: " It is quite evident that the Paris costs of production are very incomplete, and that they are no safe guide to English steel founders. Neither are the prices of the South Wales manufacturers anything to guide us in this matter. And we must remind you that we have had a much longer and more varied experience as steel founders than M. Robert, and that our knowledge as to costs and the trade generally is, to say the least, much more likely to be reliable than his."

Robert had reduced his demand to a flat rate of 5s. a ton, but it was stated that " 5s. per ton is too much on wheels used in locomotion, but considering the difficulties of your position in relation to your French associates in this matter, we would agree to try the process at that royalty." (Incidentally, the two provisional licencees referred to were Ruston Hornsby & Co. and John Brown & Co.). Writing again to Sandars, Woodward expressed himself as follows: " I must tell you candidly that I felt at a great disadvantage in discussing this matter with M. Kennard—he is so much older than I am, and his experience in general commercial affairs is so much more extensive than mine. I cannot bring myself to be so positive in the presence of such a man as I might be in conversation with a younger, altho' I know that my knowledge and experience on this particular subject are much more accurate than his. Take the case of loco. wheel centres: 10s., 8s. 4d., or 7s. 1d. a ton would, in the majority of cases, put us out of the market altogether when competition is strong. And I really cannot see that

there is any advantage in cost of production by the Robert over a properly worked open hearth. But the facility with which the Robert is worked is very attractive: although we can only judge of that from from few observations, and difficulties may crop up in actual working of which we know nothing.

"We neither want nor intend to spend money in costly experimental plants. We are in business with a moderate capital—ample for our purpose—and we intend prosecuting it to the best advantage with the best appliances and with the least amount of worry and trouble to ourselves!"

Robert now asked the firm what royalty they would be willing to pay above 5s. and to this the firm would not officially reply, having given facts and figures they knew to be trustworthy; but in a private letter to Sandars, Woodward wrote: "Many firms have taken up the manufacture of steel castings and have lost money heavily and given it up. There are others who are in the business because they cannot help it—not because they like it! And it has yet to be proved that English engineers will look favourably upon castings made by any other than the crucible and open hearth processes."

At last, on August 4th, the Robert Company gave way, and suggested 5s. a ton royalty on the invoice weights of castings, and 2s. a ton on the invoice weight of ingots, to which the firm agreed, it being understood that the licence they were taking applied only to the Robert converter, not to the cupola furnaces or blowing engines.

No Working Drawings

Naturally, to enable them to instal the process, the firm required proper working drawings, and now trouble began. On August 27th, having received some photographic copies of drawings from the Robert Company, the firm wrote: "We cannot very well use the photocopy, as it is not correct to scale. What we should have are proper drawings to scale and dimensions marked thereon, which we can put in the hands of engineers to quote to." They also asked for detailed specifications of parts and materials.

The Robert Company, operating from 28 Victoria Street, Westminster, now sent drawings of the converter and chariot, which Edgar Allen & Co., Ltd., found "of no use to us whatsoever at present, as the detailed dimensions are not given, and are only useful for erecting." The firm were planning for two converters and three cupolas, with blowing engine, etc., but intended to have one fixed converter and one cupola to start with to "prove the process."

Sandars of the London house of Robert had an interview with his chief, the inventor himself, during September, 1890, on which he reported, drawing the following reply from Edgar Allen's: "We should think we (you, Mr. Sandars and ourselves) are all equally astonished at M. Robert's audacity. Mr. Worton of Blaenavon" (whose second-hand converter the firm was considering as a possible purchase) "was good enough to send us a tracing shewing M. Robert's ideas as to what (in his opinion) a foundry should be—a wretched arrangement, we think. Consequently, we don't propose to trouble M. Robert for 'plans.' What we ought to receive from you is a detailed drawing and working specification of the fixed converter and its attachments."

By the beginning of October, 1890, a blowing engine had been bought, and negotiations for the Blaenavon Company's Robert converter were proceeding, but still no details and proper drawings came from the Robert Company. To Blaenavon, Woodward wrote: "we can buy the apparatus new for considerably less than the sum you name, viz., £200 . . . formerly M. Robert used cast iron gearing and cast iron gudgeons, but . . . now he uses steel gearing and steel gudgeons. The prices we have taken are for steel. Are you satisfied that your apparatus has steel gudgeons and steel gear? If so, we are prepared to give you £100 net cash on trucks at Blaenavon . . . The gearing is somewhat antiquated, and . . . we purpose using hydraulic power."

At this price the converter was bought, but November came, and still little assistance came from the Robert Steel & Iron Co., Ltd. "If we had been entirely dependent on you," said Woodward on November 7th, "we should not have been able to start at all."

Cost of Plant

The steel foundry was at work, however, and expenditure on it, Woodward reported to Allen on January 7th, 1891, had been less than £6,000. Ten days later, in a letter to the same person, he wrote: "It is very gratifying to Wells and to me to know that our estimates for foundry expenditure have not been exceeded . . . In regard to working capital for the foundry, I think £2,000 will suffice. And I arrive at it in this way. We have 36 pots × 150 lb. per pot per day. This I take at 2 tons of finished castings per day—say 10 tons per week—at an outlay for materials; wages; repairs; £1 per ton interest on capital; office charges, etc., etc., of £15 per ton (it will, I think, be less per ton). Multiply this by 10 tons = £150 × 13 weeks (= one quarter's credit) = £1,950 outlay per quarter. Some of our accounts will be paid before the end of the quarter. This £2,000 is the figure I put down originally, i.e., in March last."

By good fortune, it has been possible to trace particulars of the actual sums involved in establishing the foundry, incurred up to the end of December, 1890. They are as follows:

	£	s.	d.
Buildings	3,650	7	7
Gas pot furnaces and muffle	905	17	4
General services a/c (relaying sidings, etc.)	126	5	2
Producer and flues	356	15	0
Stove	203	12	0
F. and M. engine a/c	390	1	10
F. and M. machine shop	592	4	9
F. and M. pattern shop	169	14	7
F. and M. smiths' shop	175	4	9
F. and M. moulding shop	376	15	7
F. and M. gas pot furnace	119	12	6
F. and M. fettling shop	136	19	10
Hydraulic service	273	2	11
Loose tools general service	117	16	2
Loose tools pattern shop	13	1	7
Loose tools engine a/c	1	3	2
Loose tools moulding shop	259	4	5
Loose tools smiths' shop	22	2	2
Loose tools fettling shop	8	4	10
Loose tools gas pot furnace	55	11	10
Loose tools machine shop	10	15	10
Stores	11	1	2
Bricks and mortar	255	18	9
Lighting a/c	37	19	10
Patterns a/c	7	15	8
	8,279	9	3

It will be observed that the above makes no reference to the Robert converter and equipment. This is because gas pots were used at first for making the steel castings, in case the Robert process should not be a success. Later,

these pots were dismantled as far as the steel foundry was concerned. The cost of installing the Robert equipment has also remained on record and is given below :

	£	s.	d.
Blowing engine	225	0	0
Converter	100	0	0
Cupola	80	0	0
Roof	363	10	0
Receivers	45	0	0
Hydraulic lift	22	10	0
Plates and girders for lift	65	14	5
Salary of operating engineer	110	11	7
Wages digging well for lift, foundations, etc.	139	5	1
Sundries	65	15	3
	1,217	6	4
Two hydraulic cranes	225	0	0
	1,442	6	4

Not included in the above are additional items such as galvanized sheets for the sides and ends of the building, erection of the lift, converter, cupola, cranes, etc. Further items of expenditure for what was known as the gas crucible foundry included the following :

	£	s.	d.
Furnace in smiths' shop for heating wheels to press on to axles	40	0	0
Vertical boiler to supply steam to producer instead of taking steam from present boiler, and fixing	45	0	0
Cart weighing machine and fixing	50	0	0
One 6 in. or 8 in. lathe	50	0	0
One 10 in. slotting machine	70	0	0
Machine for centring axles	20	0	0
Hollow spindle lathe	45	0	0
Fittings, etc., for laboratory	50	0	0
	370	0	0
One drying stove and one annealing stove	250	0	0
Fixing No. 2 boiler and shed over it	100	0	0
Three stove carriages	45	0	0
Shanks for carrying steel to moulds	20	0	0
Two hydraulic cranes and fixing	240	0	0
Galvanized sheets for sides and ends of building and fixing	60	0	0
C.I. connecting pipes for steam and air	25	0	0
5 ft. brick wall on east side of building, erecting and lining cupola and converter	150	0	0
Moulding boxes for 6 months	250	0	0
	1,510	0	0

As the foundry developed, the following items were added :

	£	s.	d.
Extension of sidings to coke furnace	50	0	0
Fixing truck weighing machine	30	0	0
Fixing turntable in space between fettling shop and pattern shop	30	0	0
Sidings to cupola, to pot shed and to fettling shop, and 2 ft. 6 in. tramway from present moulding shop through new dept. and yard to fettling	60	0	0
Four trams for 2 ft. 6 in. way	20	0	0
	190	0	0

According to the records, the gas furnace was ready in October, 1890, and melting began early in the November. By January 22nd, 1891, the firm were working 24 pots only, 3 casts a day. This smaller number was partly owing to patterns not being ready and partly to "getting thro' with orders." By this time, according to reports, Robert in Paris was blowing only about 1 day a week, and he refused to allow any man from Edgar Allen & Co., Ltd., to study the process at his works for more than 24 hours. It should be noted that the firm had succeeded in obtaining the services of a French foundryman, Alexandre Tropenas, as engineer and operator of the Robert process at their works. To prevent this news from reaching the ears of Robert, who, learning that the foundry had begun working, wished to send a man of his own over for this purpose, the firm in all correspondence with third persons referred to Tropenas as "Italiano."

Foundry at Work

The reference to the fact that the foundry was at work should not be taken to mean that the Robert process was working. It was not, but the expectation was that operation would begin by the middle of March, 1891. The signed licence had still not been received from the Robert Company, and on February 28th, Woodward wrote to Allen : "We don't want Robert's chief engineer: and we won't give him (Robert) a sketch of our 'installation.' Wells has seen three installations on the continent and says ours is decidedly the best arrangement, and Tropenas does not want his ideas to be appropriated by people who may be his competitors on the continent.

"We don't want to send a moulder to Paris. Both Wells and I and Tropenas are clear on that point. He could learn next to nothing there that we do not already know and he might teach them a good deal unwittingly.

"Tropenas says there are many things and methods about our works of which Robert and his people know nothing, and which they would pick up if they were allowed to come there." (Tropenas had himself invented a process which was to supersede the Robert, and which was later pioneered by Edgar Allen & Co., Ltd.). "... Tropenas is highly amused at Robert saying he would send his chief engineer at his own expense. Exactly ! what the operator cannot see or remember, the chief engineer might see and remember ; two are better than one. Therefore, what we intend is to get the apparatus to work under Tropenas' management, and if we are satisfied (as no doubt we shall be) then say to the Robert Company, 'We thank you for offering to send us an operator, but we can do without him.'"

At last, on March 31st, 1891, Woodward was able to write to Allen : "We had a trial 'blow' this afternoon to test the apparatus and to find out defects or things required to secure success." A fortnight later, the firm wrote to the Robert Company, who had moved to College Hill Chambers, Cloak Lane, London, E.C. "You have told us that if an operator is sent from Paris you will have to pay M. Robert £400. We have no wish to put you to this or any other expense ... you have been unable to render us any assistance in designing and putting down the installation. The tracing of the converter you sent us was useless as a working drawing—fortunately we were able to buy a second-hand converter which is sufficient for the present. But you were unable to give us any information as to the blowing engines, the air receivers, the cupolas, the numerous connexions, etc., etc. Consequently, we were left to take the course we thought best, and this inability of yours to provide us with absolutely necessary information has cost us between £500 and £1,000, in which cost there is not a farthing for any plant of any kind or bricks and mortar, etc.

"It has recently come to our knowledge that the firm in Milan which has acquired the Robert process for Italy

charges £1,000 payable after the first steel has been turned out satisfactorily. For this £1,000, drawings are supplied, the erection of the plant, etc., is superintended and the whole thing is started and proved. The royalty is fr.3 per ton = say 2s. 3d."

Other unpleasant facts learned were brought to the Robert Company's notice, and the letter concluded: "we should be prepared to release you from your obligations to us in the matter of an operator provided the royalty be reduced to not more than the figure we have named." Robert was unable to deny the facts adduced in the above letter, and his own London Company is on record as having verbally referred to him in an interview as "a damned scoundrel."

Up to the end of November, 1891, the firm (Edgar Allen) had sold about 120 tons of castings, the steel for which had been melted in the Robert converter. By the end of January, 1892, they were becoming doubtful whether they wished to continue using the Robert process, and on March 4th, in view of the increasing success of the Tropenas process, the definite decision was conveyed to the Robert Company that the firm had abandoned the idea of taking a licence for the Robert process, and had given instructions to dismantle and disuse the converter. On March 7th, this was followed up by a letter indicating that manufacture of steel by this process had ceased. A final cheque in settlement of outstanding royalties was sent, and this particular chapter of foundry history closed.

With its new Tropenas process, however, the Edgar Allen steel foundry went on from strength to strength, as it could never have done with the Robert process, which was a virtual failure, being uncertain and unreliable. The pot furnace was done away with soon afterwards, and today the steel foundry in question is one of the largest and best-organized in the country.

H.F. Heating Aids Production of Hydraulic Gear

A FEATURE of the hydraulic gear manufactured by Epco, Ltd., is its all-steel, brazed construction, which gives a combination of light weight, strength and reliability. The absence of castings eliminates hydraulic troubles due to porosity, and allows the Epco Minor jack, which is capable of lifting any load up to three quarters of a ton, to be constructed with a total weight of only 32½ lb. A pump providing pressures up to 50 tons/sq. in. can be made truly portable in the same way, thus saving time and expense in dismantling and reassembling when moving from one job to another.

The all-fabricated method of construction of the Epco gear calls for a very high standard of brazing, many of the joints having to withstand heavy loads and high pressures. For this reason, high frequency induction heating is used, and reliable joints are produced consistently without regard to the skill of the operator.

Several advantages are derived from the use of induction heating. The heat is localised to the metal around each joint so that the remainder of the workpiece remains comparatively cool, and unnecessary heating is eliminated. Distortion, often a characteristic of other methods of heating, is negligible, and long cooling periods are avoided. The brazing material is applied as a wire preform so that the amount used is kept under strict control. This effects savings in both time and material, since a subsequent cleaning operation to remove surplus metal is unnecessary.

The H.F. induction heater employed has an output of 5 kW. at a frequency of 5 Mc./s., and was designed and made by The General Electric Co., Ltd. It is used with a range of easily interchanged heating inductors as a general purpose machine, not only for brazing, but also for soft soldering and case hardening. The brazed joints are made with Johnson Matthey's Easyflo solder, which melts at a little above 600° C.

The generator is shown in Fig. 1 where it is being used in the assembly of the Epco Double Speed Flexi-Force, a hydraulic pump which forces oil out through a high pressure rubber hose connection to a hydraulic ram, and provides pressures up to 50 tons/sq. in. In this picture, an end piece is being brazed to the cylinder, an operation

Fig. 1 (left).—G.E.C. 5kW induction heater at the Star Works, Leeds, of Epco, Ltd. Fig. 2 (right).—Assembly of the Double Speed Flexi-Force hydraulic pump. The handle assembly is brazed with the two turn inductor in 20 seconds. The end pieces are brazed to the 30 in. O.D. cylinder with the single turn inductor; each piece being completed in 2 minutes.

Fig. 3.—Assembly of the Epco Minor hydraulic jack. The pump unit is brazed to the cylinder in 1¼ minutes and the joint round the inlet to the cylinder in 20 seconds.

Fig. 4.—A steel claw, one of the accessories for use with Flexi-Force pumps, being case hardened. A hardening compound is used and the heating time is 3 minutes.

taking 2 minutes. Other joints made on the same pump are shown in Fig. 2. Similar brazes are carried out on the Junior and on the Standard Flexi-Force pumps.

The induction heater is used for both brazing and soldering in the assembly of the Epco Minor, Atom, and Forton jacks, some of the applications being shown in Fig. 3. The same illustration also shows the simple heating inductors used; they are made from high conductivity copper tubing, to allow water cooling. The use of special coil blocks, a feature of G.E.C. induction heaters, facilitates the rapid changing of inductors, at the same time ensuring thoroughly watertight connections.

Nickel Alloy Welding Film

A NEW 16 mm. sound film in colour has been produced by Henry Wiggin & Co., Ltd., to instruct welders and others in the techniques of joining the various wrought nickel alloys which this company supplies. While the film is concerned mainly with Monel, nickel and Inconel, it includes reference to Nimonic 75 sheet fabrication and also to Corronel B, a corrosion-resistant alloy of recent introduction.

The first requirement in welding all the high nickel alloys is cleanliness, and the film begins by indicating the various methods adopted to remove all contamination and oxide scale. Oxy-acetylene welding can be used for joining most of the high-nickel alloys, although it is not generally used with Nimonic 80, 80A and 90. The film shows the correct flame setting for the various groups of nickel alloys—reducing for Inconel, K Monel, Nimonic 75 and Brightray alloys, but nearly neutral for Monel, nickel and Corronel B. Methods of controlling distortion during welding are shown, together with examples of types of jigs that have been proved useful. Various types of joints suitable for various gauges of sheet are shown in some detail to indicate the type of edge preparation that is recommended.

The next section of the film shows the application of the argon-arc processes which can be used for all the high-nickel alloys using special welding wires. The main points which require attention are emphasised and automatic argon-arc welding of Nimonic 75 is included. Metallic-arc welding of the high-nickel alloys is widely used, and again the film gives detailed instructions on current ranges and electrode sizes, preparation of welds, etc. Close-ups compare the appearance of welds in nickel, Monel, Inconel, Nimonic 75 with one in mild steel.

Resistance welding of Monel, nickel, Inconel and Nimonic 75 by spot, stitch and seam welding is now well established, and shots are included of the setting up of machines for a production run. As the advantages of flash-butt welding for particular applications become more widely known, increasing use is being made of this process, as in the example shown in the film of the welding of rings in Nimonic 75 which are produced for the gas turbine industry by flash-butt welding of extruded sections.

The film indicates that, if special care is taken to avoid contamination, no difficulty should be experienced in welding any of the high-nickel alloys, providing the recommendations outlined are followed.

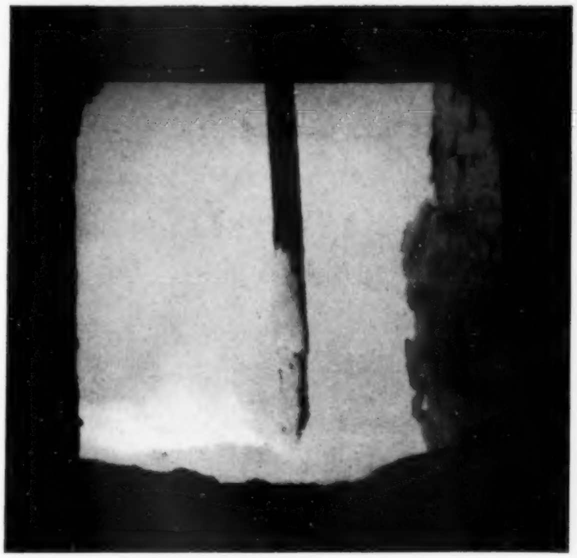
The film is available on loan without charge to local Engineering Associations, Training Officers, etc., and application should be made to The Publicity Department, Henry Wiggin & Co., Ltd., Thames House, Millbank, London, S.W.1.

British Oxygen Brinsworth Expansion

THE capacity of the Brinsworth (Yorkshire) works of British Oxygen Gases, Ltd., is being increased by the addition of a second large liquid oxygen plant to meet increased demands for oxygen in this important industrial area. Its liquid oxygen storage tank will be of the largest size in use in the country. New offices have also been built at Brinsworth and these will become the main offices for the Company's activities in the Yorkshire District. They will be complete with a canteen and a demonstration shop for the Technical Sales Department.

Oxygen in Steelmaking

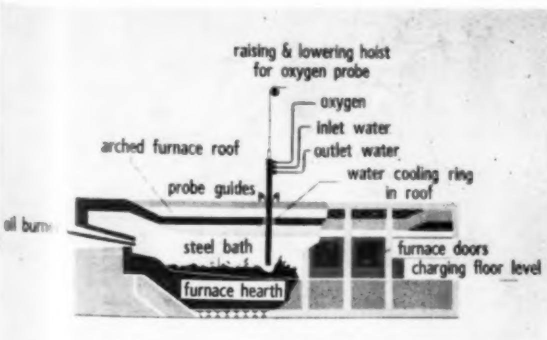
New Tonnage Plant at Margam Inaugurated



Oxygen being fed by means of a probe into a bath of molten steel

HISTORY was made on August 1st, 1956, when the Home Secretary and Minister for Welsh Affairs, Major the Rt. Hon. Gwilym Lloyd-George, M.P., started up the British Oxygen Company's new tonnage oxygen plant at Margam, South Wales, by pressing a button at Bridgewater House, the Company's London Headquarters. The unusual nature of the occasion lay in the fact that those present at Bridgewater House were able to see the plant started up, to make a "tour" of the works, and to see oxygen being used in a steelmaking process. This was made possible by a closed-circuit television link installed specially between Margam and London (approximately 200 miles) with the co-operation of the B.B.C., the G.P.O., the Marconi Company and the Steel Company of Wales. The commentators at Margam were Wynford Vaughan-Thomas and Max Robertson, and a two-way sound link enabled questions to be answered directly from Margam during the Press Conference which followed. In all some £50,000 worth of mobile equipment was involved in the sound-vision link-up.

The new tonnage oxygen plant is the first to be brought into operation in the United Kingdom. It has a capacity of 100 tons per day, and is to be followed shortly by a companion plant at Margam which will have double the capacity. The purpose of the installation is to supply oxygen in tonnage quantities to the adjacent Steel Company of Wales plant, where it will be used in steelmaking processes. In addition to the two Margam plants, 200 tons per day plants are announced for Scunthorpe and Middlesbrough, and 100 tons per day installations for Consett and Ebbw Vale. All these plants are to come into operation one after another during 1956-57 and 1957-58, and the capital expenditure involved is between £3m. and £4m.



Diagr... showing position of oxygen probe during ...fining operation in open hearth furnace.

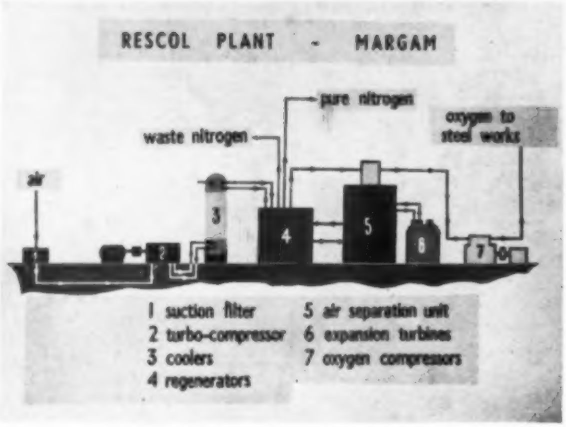
Applications of Oxygen in Steelmaking

The principles in regard to various applications of oxygen in steelmaking, and in regard to open hearth practice in particular, have been known for some time, but their development to optimum performance and their introduction as sound operating practice has been achieved through individual steel companies, the British Iron and Steel Research Association and the British Oxygen Company working freely in conjunction with one another.

As a result of developments in open hearth and Bessemer practice, the tonnage use of oxygen has become perhaps the most decisive technical development seen in British steelmaking since the war. In practice trials with certain of the steel companies, increases in output of 15% and 25% for different processes have been demonstrated, and gains of that order are a significant contribution to national output.

There are a number of ways in which oxygen can be used in steelmaking, depending on whether the Bessemer, open hearth, or electric furnace process is used.

(1) In the Bessemer process, a 9% oxygen enrichment of the air blast results in a shorter blowing time and the possibility of increasing the scrap consumption. Increases in output up to 15% are possible.



A flow diagram of the process of making tonnage oxygen used at Margam.

(2) Of particular interest is a process using a mixed blast containing oxygen and steam. Not only does this development allow of an increase in output up to 20%, it enables low nitrogen content steel of high quality to be made by the Bessemer process—an achievement quite impossible without the use of oxygen.

(3) A 9% oxygen enrichment of the air blast in a side blown Tropenas converter, not only reduces the blowing time but also obviates the need to add ferro-silicon as fuel and provides hotter metal. The output may be increased by 20%.

(4) In the foundry, iron for the Tropenas converter is often melted in the cupola. Here again, 2% oxygen enrichment of the cupola blast speeds up the melting rate to such an extent that a 20% increase in steel output is made possible.

(5) The use of oxygen for pre-treating blast furnace metal in the ladle or mixer permits speedy reduction of the silicon content prior to charging into the open hearth furnace, and in this way 15% greater output is attainable. For a process using oxygen in a 50 ton rotating furnace, an increase in productivity of more than 50% is claimed.

(6) In the open hearth furnace itself, faster melting of scrap and an increase in output of 15–20% result from flame enrichment by oxygen.

(7) The beneficial effects of oxygen injection in the bath of the open hearth furnace depend on the production of sufficient iron oxide in the metal and slag to maintain the maximum rate of oxidation and the mechanical action of the jet in removing carbon monoxide from the reaction zone. The increase in rate of carbon removal results in an increase in output of 12–15%.

(8) Faster removal of carbon can also be achieved by oxygen lancing in the electric arc furnace, when the output may be increased by as much as 10%. A special application in the electric furnace field is the reduction of carbon in stainless steels, which has solved the problem of disposal of stainless scrap. It also allows the use of higher chromium ferro-chrome and reduces the loss of chromium in the slag.

The advantages to be gained from the use of oxygen in steelmaking are real, but as in any other industrial operation the economics of the process have to be taken into account. Only reasonably cheap oxygen can ensure economic success, and during the post-war years a number of chemical and metallurgical companies in the U.S.A., South Africa and various European countries have erected tonnage oxygen plants within their own works. In this country, however, the oxygen industry has adopted the policy of erecting such plants in steel-making districts with the object of piping supplies to the steelworks in the area. In his speech at the inauguration ceremony, Mr. J. S. Hutchison, Chairman of British Oxygen, gave some interesting figures on capital costs. The capital cost of an open hearth steel plant is about £10 for each ton per year of steel produced, and the capital cost of a tonnage oxygen plant and ancillaries is in the neighbourhood of £10 for each ton per year of oxygen. Thus an annual output of 100 tons of steel can be increased to 110 tons by the employment of one ton of oxygen at a capital cost of £10, compared with the £100 that would be required to achieve the same increase in output by extension of open hearth capacity in the traditional way.

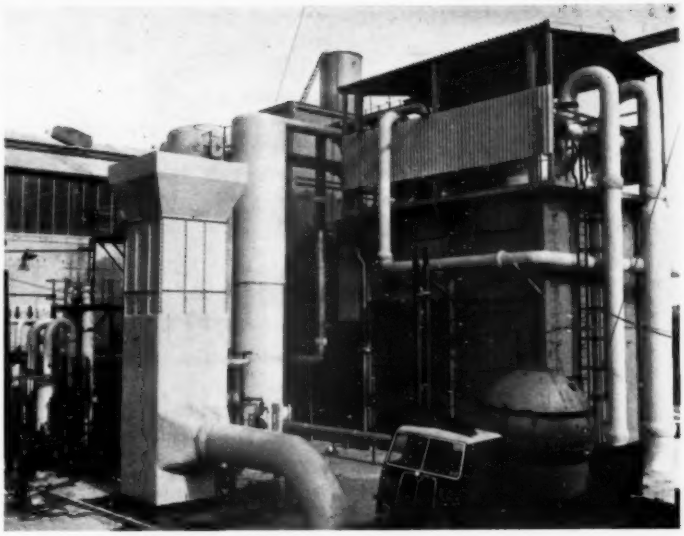
General view of the British Oxygen Company's works showing Abbey Works in the background.

New Plant Design

As has been mentioned, the principle of the application of oxygen in steelmaking has been known for some time, the present day interest lying in its application to British conditions and practice. Equally, the principle of the plant for making oxygen has been known for many years, and it can fairly be said that before the war the "know how" of the plant building side, which is vital, depended greatly, if not entirely, on Continental and American knowledge and practice.

The Margam plant is of a British design, unique to the British Oxygen Company, whose scientists and engineers developed it.

Amongst the particular features of the process, exemplified in the Margam plant or in later models, is a flexibility within wide limits in the amounts of gaseous and liquid oxygen which can be produced. This feature has substantial influence on the economics of operation, as the capacity of a plant not immediately required can be turned to liquid oxygen, which can be taken into the ordinary liquid oxygen distribution business. Another technical advantage is that the production consists of high purity tonnage oxygen. For a time, medium purity oxygen was the only feasible product from tonnage plants, and such gas was only suitable for some purposes. Without significant effect on costs, the British Oxygen Rescol plants produce high purity oxygen, which gives benefit in certain steel applications, suits all processes, and confers the great advantage of complete flexibility between one use and another.



View showing regenerator unit with column in the background

The New Plant

The tonnage oxygen plant is not the British Oxygen Company's first venture at Margam. Since 1952 they have been supplying oxygen to industry in general, either compressed into cylinders or in liquid form. In addition, oxygen has been supplied to the steelworks both by means of a liquid oxygen evaporator installation at the steelworks, or through a direct pipeline from the British Oxygen works. A nitrogen/hydrogen gas mixture has also been supplied to the steelworks by pipeline; this mixture is used in bright annealing.

Single Column Process

The new tonnage oxygen plant is of the Rescol type—the term Rescol standing for Regenerative Single Column Process. Regenerators are alternately operated heat exchangers, the purpose of which is to cool the air to its dew point (in this context the temperature at which it begins to liquefy), to remove simultaneously the moisture and carbon dioxide, and to warm to ambient temperature the separation products, oxygen and nitrogen. The single column has thermodynamic advantages, and in fact the operating pressure of the Rescol process is lower than that of any other known tonnage oxygen process.

The cold requirements of the process are covered by expansion turbine sand the Rescol cycle permits variation of the cold production within a fairly wide range. Where necessary, a Rescol plant can be modified so as to obtain such a variation in cold production that it becomes possible to produce an appreciable quantity of liquid oxygen, which can be stored or exported during periods of reduced demand for gaseous oxygen. The plant also produces a certain amount of nitrogen of high purity.

Air Intake, Compression and Cooling

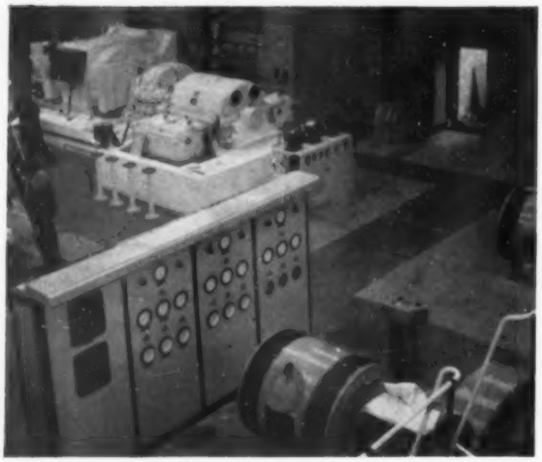
Air enters the plant at the intake at atmospheric pressure and passes via a suction filter to the turbo-compressor. This is a multi-stage machine handling large quantities of air, running at 9,000 r.p.m. and driven through step-up gearing by an electric motor. During its passage through the compressor the air is heated, and it is necessary, therefore, to cool the compressed air before it enters the regenerators. Cooling is carried out in large towers, packed with porous material of large surface area, where the air comes into direct contact with cold water.

Regenerators

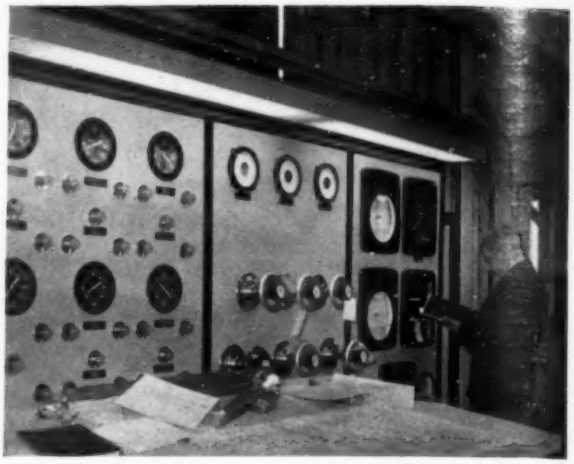
The cooled air then passes to the regenerators, which comprise a number of separate vessels located in a large box—the cold box—which is filled with insulating material to limit ingress of heat from the surroundings. To achieve the changeover from one regenerator to the other, the streams to and from the regenerators are switched by means of servo-operated valves which, together with the inter-connecting pipework, can be seen at the top of the regenerators. At the cold ends other valves are required and these are operated automatically by the changes in pressure.

The regenerators are packed with materials of very large surface area per unit volume, and this provides

Air intake and silencer.



Main air compressor with oxygen compressor control panel in the foreground.

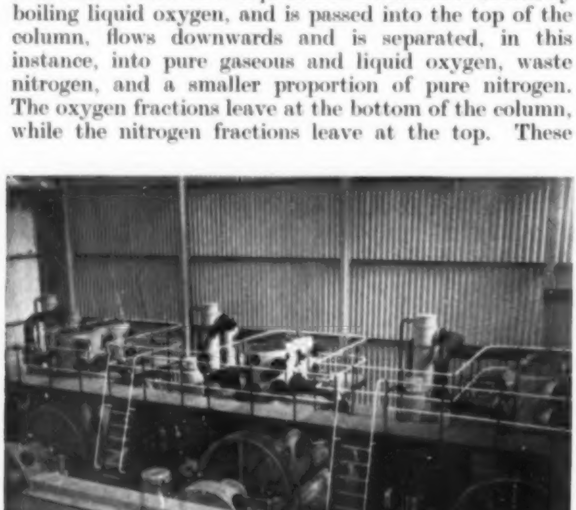


Section of the main control panel.

adequate surface for the exchange of cold between the returning products—oxygen and waste nitrogen—and the packing, and, in turn, between the packing and the air. The air is, therefore, very thoroughly cooled during its passage through the regenerators, and then passes to the air separation unit at a temperature of about −180°C. The regenerators also act as very efficient purifiers for the air, removing condensable impurities such as water vapour and carbon dioxide.

Air Separation Unit

In the separation unit, the air is further cooled and prepared for rectification in the separation column. The column is basically similar to that used in other industries such as oil refineries and distilleries, but special attention is paid to limiting the size to a minimum, so as to reduce heat inleak. The air is liquefied in a condenser cooled by boiling liquid oxygen, and is passed into the top of the column, flows downwards and is separated, in this instance, into pure gaseous and liquid oxygen, waste nitrogen, and a smaller proportion of pure nitrogen. The oxygen fractions leave at the bottom of the column, while the nitrogen fractions leave at the top. These products are passed back from the air separation unit and give up their cold to the incoming air.



View of tonnage oxygen compressors.

The air separation unit cold box also contains exchangers for conditioning the air prior to rectification, and filters and absorbers to ensure that only pure liquid reaches the column.

Expansion Turbines

Just as the houshold refrigerator requires a source of cold to keep it going, so does the air separation unit. In this case the cold is produced by an efficient expansion turbine, in which part of the air, in gaseous form, is expanded, produces cold, and performs work, which is used to drive an electric generator. This is the opposite procedure to that in the generator, but only a relatively small proportion of the total power is recoverable. The cold produced is used to maintain the air separation unit in a state of equilibrium. Since the air is at low temperature, and as the machines work at a very high speed, they are quite small and compact.

Control Panel

The focal point of the whole plant is the control panel. From this centre, the progress of operations can be watched and all important adjustments made to the plant. Recording and indicating instruments give a record of all pressures, temperatures, flows, levels and analyses, and the principal control valves are located here. The temperatures of the regenerators can also be controlled automatically from the panel.

Gasholder and Oxygen Compressors

From the control platform, the oxygen output of the plant is regulated according to requirements. Gaseous oxygen from the separation unit and regenerators flows along pipelines to the gasholder, where it is stored. Pure nitrogen is also passed to storage, while the waste nitrogen is discharged to atmosphere.

For transmission to the steelworks, oxygen is pumped from the gasholder through the pipeline at high pressure. Three oxygen gas compressors are provided for this purpose; they are three-stage reciprocating machines, motor driven through gearing, each with a capacity of 55,000 cu. ft./hr. of oxygen. Normally, two compressors would be running, with the third as standby, for it is

essential that adequate cover should be provided for any maintenance or breakdown, the supply to the steelworks needing to be maintained continuously, week in and week out, throughout the year.

It is at these compressors that the journey of the oxygen to the steelworks commences, first through the copper discharge pipe and then through a drier (for it is necessary to maintain the oxygen at a fixed dew point), and then into the 8 in. main terminating over a mile away at the main control panel at Abbey Works.

Science Abstracting

SCIENTIFIC literature is so vast that no specialist can himself even reconnoitre more than an insignificant fraction of its total range. Yet, unless each specialist can count on becoming aware of information and data in collateral fields that might be useful to him, he cannot cultivate his own field efficiently. This being so, an elaborate apparatus of abstracts and other bibliographical or "secondary" publications has taken shape for providing signposts to the "primary" ones. The development of these, so as to realise their fullest possibilities as an aid to the progress of science as one international whole, gives rise to many problems. To help in solving them, Unesco organised in 1949 an International Conference on Science Abstracting, which made a series of practical recommendations which since that date have led the way, directly and indirectly, to notable improvements. Among these has been, for instance, the establishment of the ICSU Abstracting Board affiliated to the International Council of Scientific Unions which co-ordinates, assists, and quickens the operation of existing services.

The provisional committee set up by Unesco immediately after the Conference was later reorganised with the larger scope indicated in its present title, which is International Advisory Committee for Documentation and Terminology in Pure and Applied Science. At its meeting in London on 17th–19th November, 1955, this Committee made further recommendations, embodied in a Report now available from the Secretariat of Unesco. Some of these relate to the continuation of various efforts which have already yielded useful results: for instance, to extending the contents and expanding the circulation of the *Monthly Bulletin on Scientific Documentation and Terminology*, which (though not formally published) is mimeographed and circulated to give news of developments conducted under the Committee's advice, and to stimulate interest in them; to the accrediting of correspondents in countries which have no affiliated national committees; to encouraging the compilation of lists of scientific periodicals and to encouraging the adoption of the "Guide for the Preparation and Publication of Synopses." This last is a leaflet which Unesco supplies on request, in any of four languages (English, French, German, Spanish) for editors of scientific journals to pass on to contributors; several thousand copies of it have been distributed, and this action has helped to reduce the time-lag between the appearance of original articles and their referencing in abstract journals.

Others of the recommendations are new. Thus the Committee "would welcome any possible action being taken to encourage editors of scientific and technical abstracting and indexing services to include therein an increasing number of references to patents and unpublished technical reports." Further, it recommends that Unesco should urge them "to indicate in their publications the principles whereby they select material for notice," the expectation being that such indications, along with studies of how different categories of scientists do in fact utilise the bibliographical aids at their disposal, would assist in making the whole system more efficient.

Not all of the recommendations relate to abstracts. There are, for instance, others to the effect that Unesco should collaborate in the evaluation of the various methods now being developed for making information retrievable by coding it in electronic machines or on punched cards (the format of which, incidentally, the Committee considers it would be desirable to standardise). Yet another recommendation stresses the importance of the terminological and lexicographical work which Unesco is encouraging in many fields of science and engineering, which is described in a chapter of its report on "Scientific and Technical Translating" (and on other possible means for reducing language barriers) now completed and due to appear shortly.

6,000-lb. Titanium Ingots

THE world's largest titanium ingot-melting furnace has processed its 3,000,000th pound of metal, according to the Titanium Metals Corporation of America, Henderson Nevada. This consumable-arc, vacuum, double-melting unit, having advanced design features that differ significantly from conventional furnaces, melts homogeneous commercially-pure and alloy titanium ingots of 26-in. diameter and weighing about 6,000 lb. Provisions are built into the furnace for producing even larger ingots, 30-in. diameter and over 10,000 lb. in weight. The 6,000 lb. ingot now in production represents a sharp increase over the 4,000 lb. ingots pioneered by TMCA and subsequently standardized throughout the industry.

These larger ingots were developed for continuous-mill hot rolling of wide titanium sheet, and also for the production of forgings of large section size. New types of controls had to be devised to ensure rapid and uniform melting of the large electrodes, and to control the powerful electric arc to prevent crucible rupture and eliminate ingot voids.

The furnace, designed and built by TMCA, represents over 38,000 man-hours of design work alone, and an investment of over $1 million. The new furnace represents one step in bringing TMCA's melting capacity in line with the sponge production expansion programme currently under way at the Company's Henderson plant. This will raise sponge production from 3,000 tons to 6,000 tons per year by the end of 1956.

Correction

MAGNETIC MEASUREMENTS

WE regret that on page 66 of the paper on "Magnetic Measurements" by Mr. C. E. Webb, which appeared in our August issue, there was an error in the Vol. No. for reference No. 6. This should have read:—"6, Sanford, R. L., *J. Res. N.B.S.*, 1950, **45**, 17".

NEWS AND ANNOUNCEMENTS

Post-Graduate Courses in Physical Metallurgy

In view of the need of the metallurgical industries for more men with advanced scientific training, the University of Sheffield established a few years ago a Post-Graduate Course in Physical Metallurgy, to provide special tuition in this branch of science.

Applications for admission to full-time courses are invited from (*a*) scientists already in industry, holding a degree or equivalent qualification, who have had at least three years' experience, and wish to pursue more advanced studies in physical metallurgy ; and (*b*) recent graduates in physics, chemistry or engineering, who wish to pursue a metallurgical career. In certain circumstances, applications will also be accepted from recent graduates in metallurgy with little or no industrial experience.

The first year course will be primarily for non-metallurgists, the second year course being intended for those who have completed the first year, and for metallurgists returning from industry.

The work of the second year, for session 1956–57, will be divided into five consecutive courses, each complete in itself. The subjects covered by, and duration of, the component courses are as follows : "Metallurgical Techniques" (October 8th–November 10th, 1956) ; "Deformation of Metals" (November 12th–December 15th, 1956) ; "Thermodynamics for Metallurgists" (January 14th–February 16th, 1957) ; "Physical Metallurgy of Heat Treatment" (February 18th–March 23rd, 1957) ; and "Diffusion and Sintering" (April 29th–May 11th, 1957).

S.C.I. Corrosion Essay Competition Results

The judges in the 1956 Essay competition of the Corrosion Group of the Society of Chemical Industry have found the task of selecting the winning entry from the total of fifteen received one of great difficulty. They are, however, pleased to report that the sources of their difficulty—the wide choice of subjects chosen by entrants and the generally good standard of the entries—were very welcome indications of the usefulness of the competition.

The judges consider that the closeness between the merits of several of the entries should be recognised by an increase in the total prize money and by the award of one prize of 20 guineas and two of 7 guineas each instead of one prize of 25 guineas. They have accordingly awarded a prize of 20 guineas to J. F. Light (Bexleyheath, Kent) for his entry "The Problems of Corrosion Interference Associated with the Application of Cathodic Protection to Buried Structures" ; and prizes of 7 guineas each to R. Tate (Montreal, Canada) for his entry "Corrosion : Its Implications in Aircraft," and to M. A. Pearson (Birmingham) for his entry "Hydrazine as a Corrosion Inhibitor." They also wish to express their commendation of the entry of G. M. W. Mann (London) — "The Use of Statistics in Corrosion Research."

In assessing the entries, the judges have considered literary style, originality of thought, arrangement and development of argument. They have been impressed by the generally good level of literary quality, and have found the most common weaknesses in the omission of or inadequate attention to objections that might be raised to the views advanced, and in the presentation of the conclusions. Several entries, however, merit publication (with some amendment) and the judges feel that the competition has been of some service in providing an incentive to the production of ideas in writing. They recommend strongly that the competition be repeated.

Corrosion Meeting

By arrangement with the British Iron and Steel Research Association, The Iron and Steel Institute is organising a Corrosion Meeting to be held at its offices, 4, Grosvenor Gardens, London, S.W.1, on Friday, October 12th, 1956, commencing at 10 a.m. and continuing all day. The Chair will be taken by Dr. H. H. Burton, C.B.E., President of the Institute, supported by Dr. J. Pearson, Assistant Director of the Association.

The following is the programme of papers, with the dates of publication in the Institute's "Journal":—

The Corrosion Resistance of Low-Alloy Steels, by J. C. Hudson and J. F. Stanners, (July, 1955).

The Corrosion Resistance of Wrought Iron, by J. P. Chilton and U. R. Evans, (October, 1955).

Corrosion Resistance of Some Austenitic Cr-Ni Steels of 18/8/Ti Composition. The Effect of Variation in Chemical Composition and Thermal Treatments, by E. J. Heeley and A. T. Little, (March, 1956).

Effects of Sulphate-Chloride Mixtures in Fuel-Ash Corrosion of Steels and High-Nickel Alloys, by H. T. Shirley, (February, 1956).

The Stress-Corrosion Cracking of Austenitic Stainless Steels : Part I. *Mechanism of the Process in Hot Magnesium-Chloride Solutions*, by T. P. Hoar and J. G. Hines. (February, 1956) ; Part II. *Fully Softened, Strain-Hardened, and Refrigerated Material*, by J. G. Hines and T. P. Hoar, (October, 1956).

Anyone interested in the subjects for discussion is welcome to attend and join in the proceedings, even though not a member of The Iron and Steel Institute. Non-members should write to the Secretary of The Iron and Steel Institute (4, Grosvenor Gardens, London, S.W.1), intimating their wish to be present ; a detailed programme and a reply form enabling them to apply for reprints of the papers and for buffet lunch tickets will then be sent to them. Early application is desirable.

Powder Metallurgy Course

A series of eleven lectures on Powder Metallurgy will be given at Battersea Polytechnic at 7 p.m., on consecutive Tuesday evenings, commencing October 2nd, 1956. Following an introductory lecture by Dr. I. Jenkins, the programme will include "Production of Metal Powder" (Mr. G. R. Bell) ; "Properties and Testing of Metallic Powder" (Mr. G. R. Bell) ; "Principles of Powder Compaction" (Mr. D. J. Jones) ; "Principles and Practice of Sintering" (Mr. D. J. Jones) ; "High Density Ferrous Components" (Dr. L. Harrison) ; "High Density Non-Ferrous Com-

ponents" (Dr. L. Harrison); "Permeable and Infiltrated Components" (Mr. J. E. Elliott); "Metals and Alloys of High Melting Point" (Mr. D. A. Robbins); "Sintered Carbides" (Dr. T. Raine); and "Metal Ceramics" (Dr. T. H. Blakeley).

Intending students should send the fee of £1, together with their name and address, in block capitals, to the Secretary, (Powder Metallurgy Course), Battersea Polytechnic, London, S.W.11.

Complimentary Luncheon to Sir Horace Clarke

The honour of knighthood recently conferred upon Sir Horace W. Clarke, D.Sc., F.R.Ae.S., F.I.M., was made the occasion of a Complimentary Luncheon given by the President and Council of the Aluminium Development Association at Claridges Hotel, London, on Friday, July 20th. Sir Horace, who received the accolade at Buckingham Palace on July 10th, was the pioneer in this country in developments which led to the use of strong light alloys in aircraft and, subsequently, in vehicles and general engineering applications.

The Luncheon was presided over by the Hon. Geoffrey Cunliffe, Deputy Chairman and Managing Director of the British Aluminium Co., Ltd., who this year succeeded Sir Horace as President of the Aluminium Development Association. The guests included directors and senior executives of member companies of the Association, and in particular Sir Patrick Hannon and Sir James Reid Young, directors of James Booth & Co., Ltd.

The President proposed the toast to the principal guest and spoke of the very long association which Sir Horace had had with the aluminium industry. He was supported by Sir Patrick Hannon, who stressed the pride with which news of the honour accorded to Sir Horace had been received in Birmingham, not only by the general public but particularly by every member of the staff and employees of the companies with which he was associated.

Sir Horace Clarke, replying, stated that he had joined the aluminium industry in its earliest days some 52 years ago, and the great faith which he had in its future at that time was now even stronger. The aluminium industry was still a young one with a great future, and he predicted that within the next 25 years aluminium would become a major competitor, even of steel, in the engineering industries.

Cold Forging of Steel

The acquisition by the Camp Bird Industries Group of Hanworth Engineering (Aircraft), Ltd., precision engineers, of Hanworth, Surrey, is a consequence of the recent acquisition by Camp Bird of the Steiner process for cold forging steel. While it is intended that Hanworth will continue general contracting work to the engineering and aircraft industries, the Company is to be re-named Cold Forging, Ltd., and part of the 36,000 sq. ft. of factory space will now be devoted to the development of the Steiner process.

It is claimed that the Steiner process will enable the manufacture by cold forging methods of many products which have hitherto had to be made more expensively by hot forging presses or automatic lathes. Among the advantages claimed are: (1) the cold forging process upgrades the steel during working, which means considerable savings in raw material costs; (2) a revolutionary, patented, steel-cutting device enables steel rod or wire to be cut and fed automatically into the cold forging press at speeds up to 6,000 operations per hour; (3) for the first time, objects of complex shape can be made by automatic cold forging methods.

At present, the steel nut making industry is largely equipped with American cold-header plant, whose high initial cost necessitates a high utilisation factor. It is claimed that the Steiner nut press will be cheaper, will afford economies in maintenance and tool changing time, and will give trouble-free service.

Prototype Steiner cold forging presses have been in operation for some time in Paris, and several steel components are being cold-forged under mass production conditions for the French Government and French motor car manufacturers. The full import of the process will not become apparent, however, until the heavier presses now being designed come into operation. Demonstrations of the Steiner presses are being planned for early 1957 in Britain, Europe and the United States. Camp Bird Industries will superintend all aspects of the development of the Steiner cold forging process. Basic research will be carried out by one member of the Group, a second will undertake the manufacture of prototype presses, while the third company—Hanworth—will be concerned with developing and manufacturing the cold forging tools and attachments required for the various presses.

Further Suspension of Iron and Steel Import Duties

Under the Import Duties (Exemptions) (No. 11) Order, 1955, the import duties on a wide range of iron and steel products are suspended until September 18th, 1956, while those on certain cold rolled sheet are suspended until March 18th, 1957. After consultation with the Iron and Steel Board about the supply position, Her Majesty's Government have decided to make a new order which, with one exception, prolongs the suspension of import duty for a further six months on those products on which duty has hitherto been suspended until September 18th, 1956. The one exception is galvanised sheet upon which the duty will be restored after September 18th, 1956. The Government have undertakings from the main consumers of tinplate that all available home produced tinplate, including the full output from the hand mills, will be taken up while the duty on tinplate and tinned sheet remains suspended.

This new Order, the Import Duties (Exemptions) (No. 8) Order, 1956, (S.I. 1097), will come into operation on September 19th, 1956. Copies of the Order may be obtained from H.M. Stationery Office, Kingsway, London, W.C.2, and branches, or from any bookseller, price 3d. (by post 5d.).

Institute of Physics A.G.M.

At the Annual General Meeting of The Institute of Physics, held in London on 16th July, 1956, Mr. O. W. Humphreys (the Director of the General Electric Co., Ltd., in charge of research) was elected President. Dr. B. P. Dudding was elected a Vice-President, Dr. J. Taylor, Honorary Treasurer, and Professor F. A. Vick, Honorary Secretary. The two new Ordinary Members of the Board elected were Dr. L. R. G. Treloar and Mr. G. W. Warren. Sir George Paget Thomson

was elected to Honorary Fellowship in recognition of his contributions to physics and his services to physicists.

The Report for 1955, which was adopted at the meeting, shows that during the year membership passed 5,000; 726 applications for election or transfer to the various grades were considered, compared with 579 the previous year. Representatives of the Institute visited seven technical colleges, which had applied for recognition, or a continuance of recognition, by the Institute.

The Institute's recently established Graduateship Examination was taken in four centres by 54 candidates, of whom only 11 satisfied the examiners. The number of candidates for the final examination for National Certificates in Applied Physics was 309 at the Ordinary level and 82 for the Higher Certificate. These figures compare with 206 and 75 respectively in 1954.

The Board has continued to comment upon and support proposals for the development of facilities for higher technical education. It accepted an invitation from the Ministry of Education to nominate a member to one of the two Boards of Studies set up to advise the newly appointed National Council for Diplomas in Technology.

Leoben Light Metals Conference

THE Third International Metals Conference was held on June 7-9th at Leoben, Austria. Organised by the Montanistische Hochschule, Leoben, with the assistance of the Austrian light metals industry, it was attended by over 350 technical representatives from nineteen countries. The activities included an exhibition of light metals applications, various social functions and a full programme of technical meetings at which about 30 papers were presented, covering all phases of the industry. The technical papers will be published later this year in the journals *Aluminium* (Aluminium-Verlag GMBH, Düsseldorf) and *Berg-und Hüttenmännischen Monatsheften* (Springer-Verlag, Vienna.)

Marine Shafting Export Order

THE Darlington Forge, Ltd., has recently received an important export order for finish-machined marine shafting. This comprises 850 tons of forgings to a total value of over £150,000, for delivery to the Continent during the next three years. This order was obtained in the face of strong foreign competition, and is in accordance with the policy of the Company to do everything possible to assist the national export drive. The present value of direct orders on the books for the export market is the highest recorded in the history of the Company; in addition a large amount of work for home customers is for eventual export.

The Oxford Study Conference

H.R.H. The Duke of Edinburgh's Study Conference in July brought together for the first time members of the Commonwealth and Empire concerned with a single problem: the impact of industrialisation upon such varied communities as those of West, East and South Africa, India and the Caribbean, as well as upon older industrial countries like Great Britain and Australia, with much to learn as well as to teach.

Two books are shortly to be published by Oxford University Press. The Conference Report, to be published in January 1957, will consist of two volumes. The first will contain all the addresses, the final summing-up and an account of the work and views of the twenty Study Groups, whilst Volume II will consist of twenty-five background papers specially contributed for the Conference.

With the title "The Challenge of Change," the second book, due to appear in November of this year, is by Laurence Thompson, and is not an abridged or re-written version of the Report, but a challenging discussion of the Conference theme, intended to provoke further thought upon that subject, and to stimulate action on the part of employers, managers and work-people throughout the Commonwealth, in the spirit of the Conference.

United Steel's New Film

THE latest film to be commissioned by The United Steel Companies entitled *Steel Road* was shown on B.B.C. television on Tuesday, August 14th in *Man of Steel*, a programme commemorating the centenary of the announcement by Sir Henry Bessemer of his revolutionary process for mass production of steel in converters. It was introduced from the Manchester studios by Robert Reid, the B.B.C. commentator on industrial affairs, and Langton Highton, managing director of United Steel's Workington Iron and Steel branch in Cumberland.

Steel Road, which is in full colour and runs for 23 minutes, deals with Bessemer himself and with the application of his invention at Workington; it was made for the company by Wallace Productions, Ltd., of London. During the forthcoming British Association meeting in Sheffield it will be shown in a special programme of films in tribute to Bessemer to take place in the library theatre on Wednesday, September 5th. The film has also been selected for both the Edinburgh and Venice Film Festivals, which are held in August.

Kemano Tunnel Obstruction

ACCORDING to a statement issued by officials of Aluminum Company of Canada, Ltd., principal subsidiary of Aluminium, Limited, measurements of the flow of water in Kemano tunnel indicate the probability of an obstruction near its centre, where the closing off of an access tunnel left an enlarged section. The possibility of a rock fall such as could cause a partial blockage is greater at this point than elsewhere in the tunnel. It will be necessary to unwater the tunnel to obtain a complete explanation of the interference with flow, and this will be undertaken in a manner planned to avoid interruption of aluminium production at Kitimat.

In the opinion of the Company's engineers, subject to the findings when the tunnel is entered, some remedial work not considered to be of a major nature may be necessary to ensure that the full amount of power will be available for the planned expansion at Kitimat during 1957, 1958 and 1959. The power presently obtainable in spite of the observed loss of head is in excess of that required to supply the Company's existing smelters at Kitimat, as well as the additional smelter unit now under construction, representing an aggregate annual capacity of 180,000 tons of aluminium to be in operation towards the end of 1956. Scheduled expansion of the Kitimat smelter calls for an additional 150,000 tons of annual capacity by 1960.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

New Cutting Oils

MANCHESTER OIL REFINERY (SALES), LTD., are now marketing a number of new cutting oils which have been specially developed for the machining of the tougher metals including Nimonic and titanium alloys.

Ferromor A and B are sulphurised cutting oils containing sulphur in an active form. They are particularly suitable for machining steels in the medium and higher tensile classes.

Halmor 9 is a low viscosity, active, sulpho-chlorinated oil designed for the machining of high tensile steels and work hardening materials. It contains no toxic materials and is therefore completely safe in use. The low viscosity makes it particularly suitable for operations where the seat of cutting is necessarily remote from the point of application of the oil.

Halmor 10 is a relatively high viscosity oil having a very high concentration of extreme pressure agents of the sulpho-chlorinated variety. It contains no volatile toxic material. The higher viscosity of this cutting fluid makes it suitable for very arduous operations of the slower type on extremely tough materials. Examples of such operations are the broaching and shaping of certain alloys for gas turbine engines.

Manchester Oil Refinery (Sales), Ltd., Twining Road, Trafford Park, Manchester, 17.

Automatic Argonaut Equipment

BRITISH OXYGEN announce the addition of automatic Argonaut Welding to their existing range of Argonaut equipment. Argonaut is an inert gas-shielded electric welding process employing a continuous consumable wire electrode, which is particularly suitable for the rapid welding of heavy sections of aluminium, stainless steel, copper and mild steel. The process has been available to British industry for the past three years but, so far, welding has been carried out by means of a hand gun.

The new Automatic Argonaut head provides a fully automatic mechanized equipment for the production welding of heavy sections of metals. The advantages of this equipment lie in high welding speed, smooth weld bead, even and controlled penetration, and freedom from porosity. It is particularly suitable for the welding of mild steel. Several of the new automatic Argonaut units have already been supplied to a number of important firms for the welding of heavy gauge aluminium.

The new head has been specially designed to maintain automatically a constant arc voltage while feeding a consumable electrode into the welding arc. It is designed to handle 600 amp. D.C. continuously, and is usable with 0·03[illegible] 0·045, $\frac{1}{16}$, $\frac{5}{64}$ and $\frac{3}{32}$ in. diameter "hard wires", i.e., stainless steel, copper, bronze and steel, and with $\frac{3}{64}$, $\frac{1}{16}$, [illegible] and $\frac{1}{8}$ in. diameter aluminium and magnesium alloy wires.

Welding longitudinal cylinder seam with automatic Argonaut unit.

The unit consists of a welding head which houses the wire feed mechanism, a water cooled machine barrel, a reel casing assembly with mounting bracket, a wire casing to feed the wire from the reel casing assembly to the welding head, a main control panel and a remote control panel. Where production welding of a repetitive nature is desired the Argonaut automatic head should be employed to obtain greater uniformity and quality in the work, and to cut costs by increased speed of welding. The heart of the mechanized welding set-up is the Argonaut head. Other devices, such as a motorised carriage unit or motorised work positioners, will also be needed, depending on the individual job, e.g., these mechanical devices will move either the head or the work, so that the weld follows the seam.

The manual Argonaut gun uses a variable speed constant wire feed motor, and arc voltage is maintained constant by the principle of self adjustment through automatic changes of wire "burn off" with changes of arc length. In contrast, the automatic head maintains constant arc voltage by varying feed speed. Constant welding conditions will be precisely maintained through the automatic speed regulation of the welding wire into the welding arc. A simple electrically controlled motor drive actuates the feed rolls. Two wire speed ranges are provided. On the low speed switch position wire feeds of about 80–350 in./min. are available, whilst on the high speed range wire feed can be varied between approximately 150–450 in./min. by rheostat control. For extra high speeds, special gears can be supplied to increase the wire speed to 750 in./min.

The main control cabinet contains less frequently adjusted controls, namely, a polarity switch, high-low wire speed switch, and basic arc length control. Meters are built into the front panel to indicate arc voltage and welding current. These meters simplify and speed up the checking for optimum welding conditions. The more

frequently used controls that the operator needs to have readily at hand are all contained in a small remote control box. This small unit is designed for convenient mounting at the operating station.

The control system also provides a circuit that may be used for starting and stopping the welding operation by switching the field current of the welding power source. A water pressure switch is incorporated in the controls so that welding cannot be started unless there is positive water pressure in the cooling system. Slow wire down-feed control permits smooth arc starting, and stub burn-off control prevents the welding wire freezing into the weld pool at the end of operation.

A 600 amp. composite dry rectifier has been designed for use with the Argonaut automatic head. It comprises a 3-phase transformer with primary tappings for 360, 380, 400, 420, and 440 volts 3-phase, 50 cycle supply, and a dry plate selenium type rectifier, fan cooled, which has automatic protection to guard against failure of fan motor. Remote control of the whole range of welding currents from 50–600 is effected by means of a rheostat controlling the current to a magnetic amplifier. A single pole 600 amp. D.C. welding contactor is incorporated in the set and is controlled through the welding head.

An H.W. tractor can be supplied with the automatic head to give speed ranges of 0–50, 0–250, 0–750 ft./hr., depending on the application.

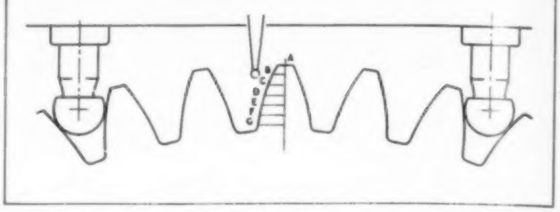
The British Oxygen Co., Ltd., Bridgewater House, Cleveland Row, London.

Portable Gear Profile Measurer

THE DAVID BROWN TOOL DIVISION, has added to its already considerable range of products a compact portable gear profile measuring instrument designed for use on large diameter gears where accuracy of profile has to be maintained within extremely fine limits, e.g., turbine gears. As the instrument will cover gears ranging from 18 in. to 16 ft. or more in diameter, and is equally efficient when testing spur or helical gears, it is a valuable contribution to the manufacture and all-round efficiency of this class of gearing.

The instrument is mounted on the gear by three spherical locators; six sets of these locators, ranging from $\frac{5}{16}$ in. to $\frac{3}{4}$ in. diameter, are supplied with each

The David Brown portable gear profile measuring instrument in use.



Diagrammatic illustration of the method.

instrument to accommodate gears of various pitches. Horizontal and vertical slides are traversed by micrometer screws and can be set in any desired position to within 0·0001 in. . The vertical slide carries a spherical-ended stylus which operates a sensitive dial indicator graduated in ten-thousandths.

The method employed to check the accuracy of the gear profile is based on the measurement of a series of predetermined horizontal and vertical co-ordinates as shown in the illustration. To commence the measuring sequence, the spherical-ended stylus is brought into contact with the outside diameter of the gear at point A, and the vertical thimble is set to zero. Next, the stylus is moved into the tooth space and then in a downward direction the distance of the first vertical co-ordinate plus the radius of the stylus sphere. The horizontal slide is then moved to enable the stylus to contact the flank at point B, following which the horizontal thimble and dial indicator are set to zero. As the next step, the stylus is withdrawn into the space and moved downwards the distance of the second vertical co-ordinate, and the horizontal slide is traversed until the stylus contacts the flank at point C and the dial indicator shows zero reading; the reading on the horizontal thimble will then show any error that may be present at this point on the flank.

This operation is repeated down the flank at the predetermined vertical co-ordinates D, E, F, and G, thus making apparent the actual profile of the gear being checked.

The David Brown Tool Division, Park Works, Huddersfield.

Quality Positional Welding Electrode

A NEW electrode has been produced by Quasi-Arc, Ltd., which is of particular interest to fabricators of oil storage tanks, gas holders and other site-erected structures. This electrode, Vertispeed, is a general purpose electrode for welding mild steel in all positions, and gives welds of high radiographic standard. It is particularly recommended for welding horizontal-vertical and vertical butt welds. A special feature is the ease of weldability in all positions which, combined with the excellent slag detachability and high deposition speed, makes it particularly attractive to the modern welder. The electrode is supplied in sizes 12 to 6 s.w.g., each in 15 in. lengths, so that full advantage can be taken of the maximum welding currents to give fast economical welding. The electrode is approved by the Ministry of Transport and Civil Aviation and by Lloyds Register of Shipping for the welding of mild steel in all positions, and complies with B.S.639 : 1952. It carries the code number E.317 according to B.S.1719.

Quasi-Arc, Ltd., Bilston, Staffs.

CURRENT LITERATURE

Book Notices

B.C.U.R.A. ANNUAL REPORT, 1955

78 pp., paper covers. Published by the British Coal Utilisation Research Association, Randalls Road, Leatherhead, Surrey. 10s.

The Annual Report of the British Coal Utilisation Research Association for 1955, recently published, contains a wealth of information concerning the Association's activities for the year ended December 31st, 1955. The early part is devoted to a general summary of the work of B.C.U.R.A. and its collaboration with its member firms and outside organisations, while the main body of the Report gives a detailed review of the research programmes carried out, and of the information made available to members and others through the publications of the Association. A financial statement is appended.

Broadly speaking, B.C.U.R.A.'s effort can be divided into two main categories: (1) practical research and development applied to the domestic and industrial utilisation of coal and its derivatives; and, (2) fundamental research aimed at increasing the chemical and physical knowledge of coal as a fuel and a chemical raw material. A close connection exists between the two, since the fundamental research provides the background essential to the more practical work. Under heading (1), the Report lists many interesting programmes and results. The main investigations on boiler firing have continued to be centred on the need to burn a wider range of coals efficiently in industrial plant and, in this connection, the development of a modified chain grate has yielded encouraging results. The loan, by the British Transport Commission, of a Royal Scot class locomotive boiler has enabled the Association to proceed further with an examination of the problems involved in using small or inferior coals in such boilers. Work on combustion in cyclone systems has been continued, as has the programme on deposits and corrosion in boilers undertaken collaboratively with the Boiler Availability Committee. During the year, also, increased support from industry and plant manufacturers has been forthcoming for an extended investigation into gas producer practice. On the domestic side emphasis has been laid upon the improvement of domestic heating, particularly in relation to the reduction of air pollution; the development of the small-pipe forced-circulation central heating system devised by B.C.U.R.A. was carried from the experimental stage to that of field testing. Research into heat balances in rooms continued, and the electrostatic precipitator for smoke measurement for domestic appliances was further applied. Instruments and their uses played an important part in the prosecution of the Association's work and, during the year, a number of instruments were either designed or further developed for special purposes. Two of the highlights of the fundamental research were the advances made in the knowledge of the oxygen-containing groups in coal, and of the ultrafine porous structure of coals, carbonised coals and activated charcoals derived from them.

Five years ago B.C.U.R.A. instituted its Coal Science Lecture, coupled with a Medal, to be given in the hope of encouraging eminent scientists to review the whole subject in the light of their specialised knowledge. In the Report, reference is made to the fact that the fourth in the series was delivered, in 1955, by Professor Sir Cyril Hinshelwood, President of the Royal Society, under the title, "The Carbon of Coal." This lecture was reproduced in the *B.C.U.R.A. Quarterly Gazette*, No. 27. More than 70 reports and published papers, written by members of the staff during the year, are abstracted in a later section of the Report and these, together with a note on over 40 unpublished lectures by the staff, indicate the vigorous activity of the Association in disseminating information about its work and progress.

The only sombre passage in the whole Report concerns the financial position of the Association. Although income in 1955 was £318,959, nearly £11,000 more than in 1954, inflationary trends overtook the hard-won advance achieved and, as a result, the Council of B.C.U.R.A. found it necessary late last year to ask members for an increase in their subscriptions. It is proposed, in due course, that this should be followed by an approach to the Department of Scientific and Industrial Research for a review of the grant-aid which B.C.U.R.A. receives from the Department.

BIBLIOGRAPHY OF HARDNESS AND HARDNESS TESTING, 1937–1955

118 pp., name and subject indexes, offset lithographed. 1955-56, Industrial Diamond Information Bureau, St Andrew's House, 32-34 Holborn Viaduct, London, E.C.1. 5s. 6d.

The compilation of this bibliography was begun in 1950, but has been delayed for various reasons, not least being the complexity of the subject matter. With the inclusion of practically all material up to the end of 1955, it is hoped to give the worker in the field of hardness, and in particular microhardness, a tool which will enable him to obtain up-to-date information on any particular branch or aspect of hardness, or to compare his own work with that of others. The year 1937 was chosen for the beginning of the bibliography as it marks approximately the date when microhardness testing was first introduced. Not only is work specially devoted to hardness testing featured, but reference is also made to work in which hardness testing was only used as one of the methods of investigation. The Industrial Diamond Information Bureau states that the price of 5s. 6d. covers only a part of the publishing costs.

Trade Publications

Alar, Ltd., have recently revised their data sheet entitled "Notes on the Heat Treatment of Aluminium Alloy Castings." Although the greater proportion of castings are used in the as-cast condition, there are a number of special applications for which high mechanical properties are required, and the purpose of the notes is to set out briefly the conditions applicable to treatment of the various alloys, the scope and limitations of the process, and the precautions to be observed. A section of the notes is devoted to heat treatment for the purpose of removing casting and other stresses.

We have received from George Kent, Ltd., Publication 925 which details the standard charts and scales available for Multelec instruments. A list of Kent standard temperature/millivolt and temperature/resistance equivalents is also included, so that comparison may be made where a customer proposes to supply the thermocouples.

Readers concerned with the applications of arc welding will be interested to learn that Lincoln Electric Co., Ltd., have recently issued a new edition of their "Weldirectory." This details the welding plant and electrodes manufactured by the company. The latter include types suitable for welding mild steel, low alloy steel, stainless steel, cast iron, aluminium and copper-base alloys. There is also a section on arc weld surfacing, and one on welding accessories and protective equipment.

An informative brochure has just been published by Compoflex Co., Ltd., giving details of the first British metallic vibration eliminator, which they have recently introduced. The vibration eliminator is claimed to be the flexible answer for situations where pipes are misaligned or exposed to movement such as vibration. Various typical applications are suggested for connecting gas, air, oil, steam and water pipes, and a complete description is given of the make up of the eliminator. There is a table giving detailed specifications of the two types of end fittings, together with the maximum temperatures and working pressures, according to whether the material used is copper alloy or Monel and stainless steel. Copies of the leaflet may be obtained from the London Flexibles Centre of the Compoflex Co., Ltd., 23–25, Northumberland Avenue, London, W.C.2, or from the Northern Flexibles Centre at Huddersfield Road, Oldham, Lancs.

A concise and easily read wall chart showing the physical properties of Meehanite metal—intended for workshops, engineering offices, drawing office staffs and buyers of castings, among many—has been produced by the International Meehanite Metal Co., Ltd. It is a condensation of the book "The Specification of Meehanite Metal." The chart is sub-divided into four sections dealing with general engineering, heat resisting, corrosion resisting and wear resisting materials. Under each division is listed the various types of Meehanite (high duty irons) in that group, and in cross reference against them are their properties. The comprehensive listing of properties—from modulus of rupture to magnetic permeability—leaves nothing to be desired in checking or selecting a type of Meehanite in the shortest possible time. The chart is invaluable when making a specification for Meehanite, whether by designers, engineers or purchasing agents. It is available on application to: The International Meehanite Metal Co., Ltd., Meerion House, 4, Downside, Epsom, Surrey.

"Wet or Dry" is the title of a leaflet recently issued by Norton Grinding Wheel Co., Ltd., which deals with diamond wheels for grinding cemented carbides and other ultra-hard materials. Particulars are given of metal-bonded, vitrified-bonded and resinoid-bonded wheels, the last-named having been developed specifically for dry and semi-dry grinding. Mention is also made of resinoid-bonded hand hones and a resinoid-bonded cutting-off wheel.

The function of Detac No. 3, the subject of a new leaflet from The Pyrene Co., Ltd., is to reduce the labour required to maintain paint spray booths in a clean and efficient condition, by denaturing the overspray and, by removing all stickiness, preventing its adhesion to reservoir walls, eliminator plates, filter screens and pumps. It is a supplementary material to Detac No. 1 and Detac No. 2, and does not necessarily supersede them, particularly where these materials are already giving maximum efficiency at an economical cost.

We have recently received a copy of the July issue of *Butterfield News*, the new-style magazine of W. P. Butterfield, Ltd., of Shipley. It is divided into two main sections, one dealing with technical and commercial features, and the other a personnel section. The former contains the second of a series of articles on "Stainless Steels" and a report of the Deputy Chairman's visit to Australasia. By thus presenting regularly a chronicle of Butterfield progress and development, it is hoped to cement relations between the Company, its customers and staff.

A.P.V.-Paramount, Ltd., are featuring their various grades of stainless steel castings on a series of blotters. A recent one deals with Paralloys M.1, M.2 and M.3, which are hardenable 13% chromium corrosion resisting alloy steels in three compositions of varying carbon content, conforming with British Standard Specification 1630 : 1950—Grades A, B and C. For many engineering applications they provide a particularly useful combination of hardness, tensile, fatigue and corrosion resisting properties.

The latest technical data booklet published by High Duty Alloys, Ltd., Slough, is concerned with sheet and plate, and has been prepared to assist users in the selection of the most suitable alloys for their particular application. To this end, following brief particulars of the Company's rolling mill products and notes on storage and fabrication, particulars are given of the nominal composition and the mechanical properties of the Hiduminium alloys available in sheet form. These range from commercial purity aluminium to alloys developed for use at elevated temperatures; in the latter case the tensile properties at elevated temperatures are given.

The August issue of *Redifon News Letter* includes an item dealing with industrial applications of the I.H. 45, 125 kW., radio frequency induction heater. This unit has been designed to provide heavy engineering and steel companies with equipment with which they can perform rapid and selective heat treatment efficiently and economically. The first production models are now being completed, and amongst applications for which equipment has been ordered are the local hardening of large diesel engine crankshafts, progressive heating of bar stock, general purpose heat treatment of gears, and annealing of stainless steel tubes. Copies may be obtained from Redifon, Ltd., Broomhill Road, London, S.W.18.

We have received from The Association of Brass and Bronze Founders a copy of a reprint from *Metal Industry* entitled "Thermal Environment." Observations of thermal environment made in 14 non-ferrous foundries showed that good working conditions could result from efficient furnace design, and a new oil-fired reverberatory furnace was designed and built to replace a conventional bale-out furnace melting aluminium for a pressure die-casting machine. Appreciable saving in fuel was accompanied by improved environmental conditions.

LABORATORY METHODS

MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

SEPTEMBER, 1956 Vol. LIV, No. 323

An Examination of the Unicam S.P.600 Spectrophotometer

By D. R. Curry,* B.Sc., A.R.I.C., and P. H. Scholes,† Assoc. Met., L.I.M.

A simplified spectrophotometer designed by Unicam Instruments, Ltd., for accurate colorimetric measurements within the visible and near infra-red regions of the spectrum is described briefly. Certain features of its performance and design have been examined under practical test conditions, and some assessment of its potential application in metallurgical analysis is made.

A UNICAM S.P.600 spectrophotometer was made available to each of the authors' laboratories for a trial period. The manufacturers claim that their spectrophotometer is a precision instrument capable of both research work to the finest limits of accuracy and of heavy duty routine analysis of all types. The following is an account of the work carried out to investigate the performance of the instrument when used as a routine absorptiometer and as a special purpose spectrophotometer in metallurgical analytical laboratories.

Design

The instrument is designed to give a single beam of nearly monochromatic light which, after passing through an absorption cell, falls on one of two photocells. The photocell output is amplified and balanced by a potentiometer calibrated in terms of transmittance and optical density.

The optical system (Fig. 1) is of the Littrow type, using a 60° flint glass prism. The mirrors are silvered on the front surfaces and the curved slit is used as entrance and exit slits in its different regions : the final beam is slightly divergent. The light source is a 12 volt 36 watt tungsten filament lamp in a well ventilated lamphouse. The wavelength range is 350 mμ–1,000 mμ, although the

* Bragg Laboratory, Naval Ordnance Inspection Department, now with Services Electronic Research Laboratory.

† Metallurgy (General) Divisional Laboratory, The British Iron and Steel Research Association.

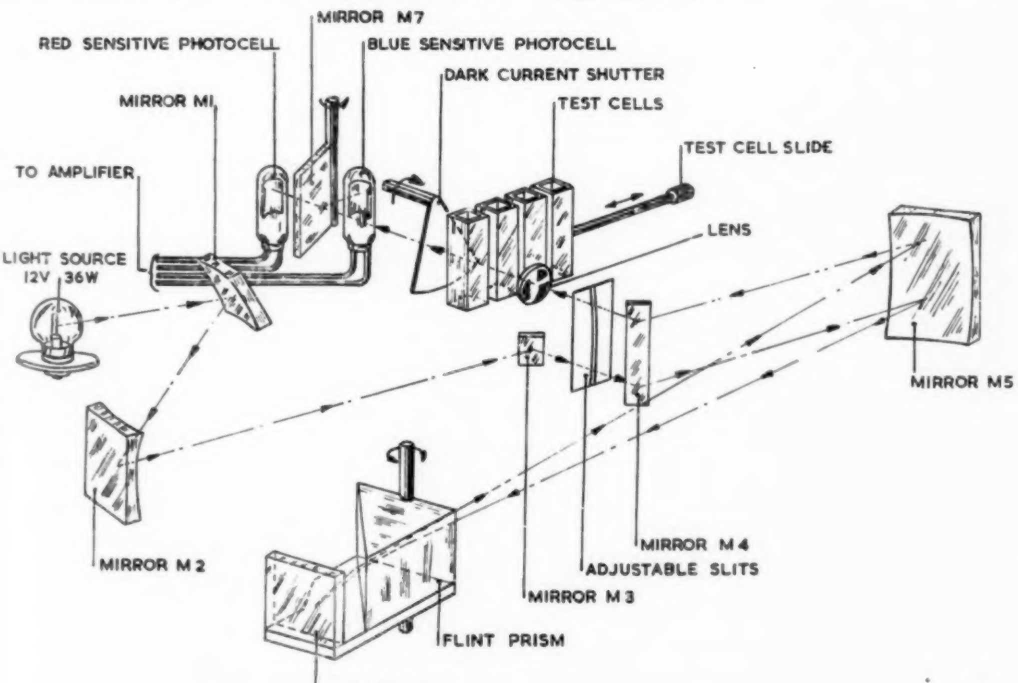


Fig. 1.—Schematic diagram of optical system of S.P.600 spectrophotometer.

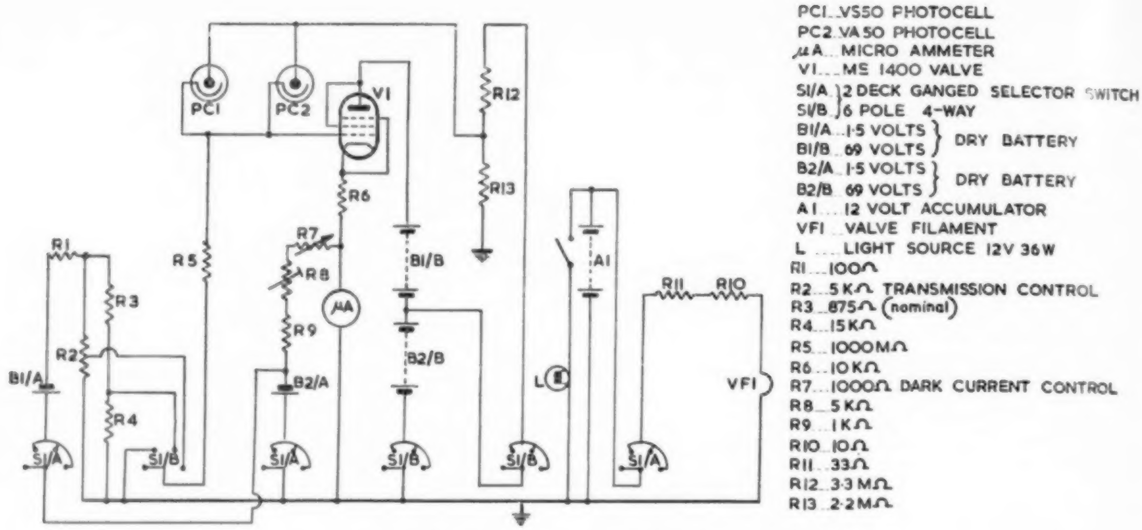


Fig. 2.—Circuit diagram of S.P.600 spectrophotometer.

system is not guaranteed to be effective below 360 mμ. For the wavelength region 350 mμ to 400 mμ, a Chance OX 7 blue filter is introduced in front of the lamp to reduce scattered light ; the filter holder also permits the introduction of other filters if desired. The wavelength of the light is selected by rotation of the prism table, which is mounted on ball bearings. Rotation is controlled by an arm bearing on a cam which is on the axis of a wavelength sca'e calibrated in 1 mμ divisions from 350 mμ–450 mμ, and then in divisions of 2, 5 and 10 mμ. The bilateral slit is spring loaded, and is closed against the spring by rotation of a rod which has a fine screw thread. The slit width control is not calibrated, but the spectral bandwidth is claimed to be less than 3 mμ over the major part of the range, and not more than 10 mμ at the extremes. The absorption cells supplied with the instrument are of fused glass, 10 mm. wide with covers, and may be obtained with optical paths of from 1 mm. to 40 mm. The cell holder accommodates four cells, movement being restricted by the use of spring slides. The holder is then placed in the cell carriage, which slides across the aperture in the instrument and has four notched resting positions.

The electrical circuit (Fig. 2) is not complex, and the problem of insulation of *R*5 (1,000 Mω) is dealt with by mounting on a separate polystyrene plate. All components are readily accessible for inspection in the event of fault, and the spares are commonly available radio components. The manufacturers 'spares service' includes prefocussed light sources and photocell housings which may easily be fitted into their correct positions. The electrical power is obtained from two dry batteries housed beneath the instrument, and an external 12 volt supply for the lamp and valve filament. The latter may be obtained from accumulators of large capacity, or from the A.C. mains through a constant voltage stepdown transformer supplied by the manufacturers.

Method of Operation

Extreme simplicity of control is one of the main principles in design, and all controls are arranged conveniently for the operator.

The instrument is switched on for a warming up period of approximately ten minutes, during which time the cells may be filled and fitted into the cell carriage so that they are at the rear of this when in position in the instrument. The desired wavelength is selected, with filter in position if required, and the red or blue photocell is illuminated by rotation of the mirror *M*7 (Fig. 1) with the selector control. The dark current is compensated first by the rheostat *R*7, balance being indicated by a zero reading on the microammeter. The main selector switch is set at 'check' (position 3), where the transmission potentiometer is 'shorted out' at 100% transmission and the shutter opened : with the cell containing the blank solution or solvent in position, the meter is balanced by adjustment of the slit width control. The selector switch is set to 'test' and the unknown solutions, in turn, placed in position : their optical densities relative to the blank are then read off by balancing the meter with the transmission control.

Test Performance

Both the instruments were examined under practical test conditions with the results given below :

As Absorptiometer

The linearity of the transmission potentiometer was examined by the procedure described by Taylor *et al*,[1,2] using a solution of potassium dichromate prepared to give a density reading of 0·100 with the instrument set against water at 0·300. The cells were placed at the rear of the cell carriage and the absorption measured at

TABLE I.—DICHROMATE LINEARITY TEST.

Water Setting	Instrument A		Instrument B	
	Density	Deviation	Density	Deviation
0·0	0·100	Nil	0·101	+ 0·001
0·1	0·100	Nil	0·103	+ 0·003
0·2	0·100	Nil	0·098	— 0·002
0·3	0·100	Nil	0·100	Nil
0·4	0·099	— 0·001	0·100	Nil
0·5	0·103	+ 0·003	0·101	+ 0·001
0·6	0·103	+ 0·003	0·098	— 0·002
0·7	0·101	+ 0·001	0·099	— 0·001
0·8	0·097	— 0·003	0·104	+ 0·004
0·9	0·102	+ 0·002	0·104	+ 0·004

405 mμ between 0·0 and 1·0 on the density scale, with the results given in Table I. The linearity exhibited was within the tolerances specified by Taylor *et al.* for the Spekker absorptiometer. It must be remembered that 'water settings' at different densities on the scale will give a variation in the bandwidth of the transmitted light, and, therefore, any possible failure to comply with the limits could be due to varying slit width and not a faulty potentiometer.

A difference varying up to a maximum of 0·007 density units in reading was obtained by placing the cells at the front of the carrier.

The series of readings detailed in Table I was repeated with differing input voltages to the constant voltage transformer. The performance of the instrument was sensibly constant in the voltage range 180–230 volts, the transformer being designed for 190–260 volts.

Two factors associated with the density scale which may contribute to errors are backlash and parallax. The former was reduced in the readings given (Table I) by setting from one direction all the time, but repeat readings from opposite directions showed differences in reading from 0·002 density units up to as much as 0·01 at the upper end of the scale. This error presumably will increase with use. The parallax error is of a slightly smaller magnitude and should not exceed 0·005 density units, depending upon the position from which the density scale is viewed.

Good consistency was shown between calibration graphs (density *v.* concentration) plotted on different occasions. The virtual monochromaticity of the light gives good straight lines, and the choice of actual wave-

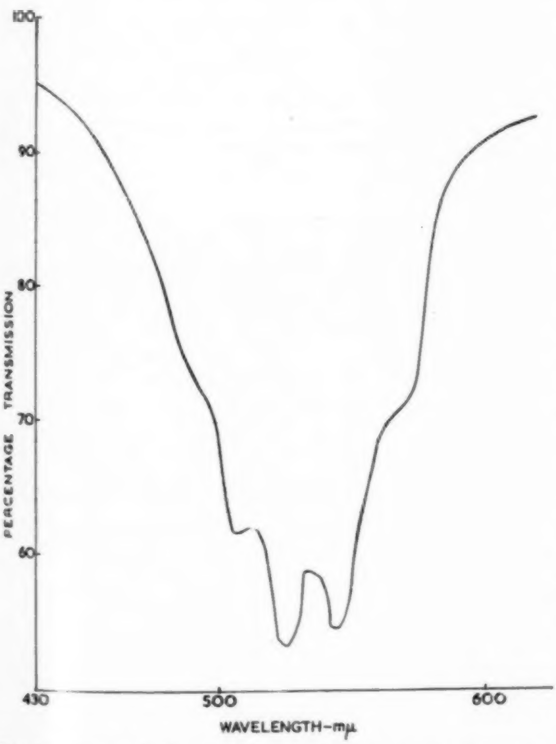


Fig. 3.—Curve obtained with S.P.600 spectrophotometer. 20 p.p.m. potassium permanganate solution; 1 cm. cell; varying slit width.

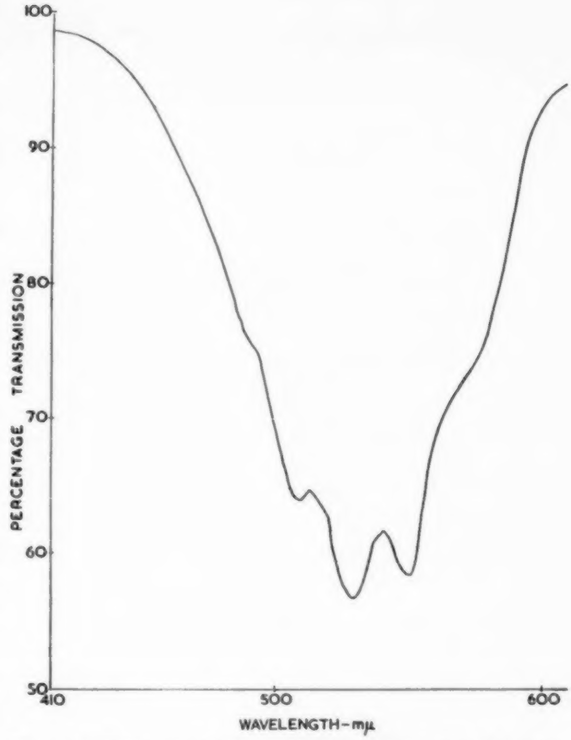


Fig. 4.—Curve obtained with Beckman Model D.U. spectrophotometer. 20 p.p.m. potassium permanganate solution; 1 cm. cell; slit width 0·04 mm. from 480-620 mμ.

length is a great asset. This advantage was shown particularly in regions in which there is no strong line in the mercury spectrum (i.e., above 600 mμ) for use with the Spekker absorptiometer. For the microchemical determination of copper in aluminium with diethydithiocarbamate, the optimum wavelength of 445 mμ was selected, and the calibration graph showed a two-fold increase in sensitivity as compared with measurement on the Spekker absorptiometer using Ilford 601 filters.

The British Standard method[4] for the determination of cobalt in steel employs Ilford 606 filters, which have a mean wavelength of transmission at 580 mμ, to measure the nitroso-R-salt complex. Readings taken on the Unicam S.P.600 at 580 mμ showed good agreement with density values obtained on the Spekker using the zero setting method.[3]

As Spectrophotometer

The foregoing examination has been made with regard to the instrument used as an everyday absorptiometer. Other trials have examined its performance as a spectrophotometer. The absorption curve of potassium permanganate was taken as a critical example and compared with results obtained with a Beckman D.U. quartz spectrophotometer.

The results shown in Figs. 3 and 4, are essentially similar, but show some slight difference in resolution, and this is shown particularly by the peak at 510 mμ. This is probably due to the lower sensitivity of the receiving and amplification circuit which, whilst giving greater electrical stability, demands an increase in slit width. This very slight variability does not in any way

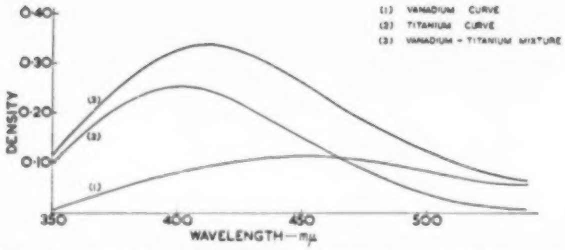


Fig. 5.—Density v. wavelength curves for vanadium and titanium peroxy-complexes (concentration of each 20 mg./litre; 1 cm. cell).

detract from the overall performance of the instrument. The dispersion of the system in the visible region is almost certainly higher than with conventional quartz 30° prism instruments.

As a more practical test, it should be possible to use an instrument of this type for the analysis of a mixture of two coloured components having absorption maxima at different wavelengths. The total density observed is an additive function of the two components, providing that Beer's law is valid.

Taking a well-known example, the resolution of the Unicam S.P.600 was examined by preparing density *v.* wavelength curves for two mixtures of vanadium and titanium coloured with hydrogen peroxide. The base solution used contained 10 ml. of perchloric acid and 10 ml. of phosphoric acid (1 : 3) to which standard solutions of titanium and vanadium were added, together with 4 ml. of hydrogen peroxide (20 vol.), and the solution diluted to 50 ml. The curves obtained (Figs. 5 and 6) agree very closely with the theoretical additive curves. Maximum deviation between theoretical and observed densities was 0·02 density units.

For a simultaneous determination of the two metals, measurements would be made at 400 mμ and 460 mμ, and simultaneous equations used to give the concentration of each component.

$$D_{\lambda_1}^{Ti+V} = d_{\lambda_1}^{Ti} + d_{\lambda_1}^{V}$$

$$D_{\lambda_2}^{Ti+V} = d_{\lambda_2}^{Ti} + d_{\lambda_2}^{V}$$

Design Features Affecting Performance

The cells themselves are difficult to clean, but this must be accepted with an instrument of this type, and is no drawback to the micro-chemist or to the analyst willing to expend a little time and trouble for the sake of accuracy. The cell holder is made of a material which, while it may not corrode, certainly tarnishes rapidly with use. Both instruments have been treated with more than ordinary care, but some slight spillages or seepages are inevitable during loading, and these have taken their toll. A through drain in the base of the cell compartment does, however, prevent serious damage to the body of the instrument, and the exit aperture of the light path is sealed with a glass window.

On the electrical side, any wear with time on the transmission potentiometer may not be uniform, and so will affect the linearity of the resistance: however, these have a long life and should not give serious trouble. The reading and backlash errors of this control have already been mentioned. The main selector switch seems to be the weakest mechanical link—it is used three times in

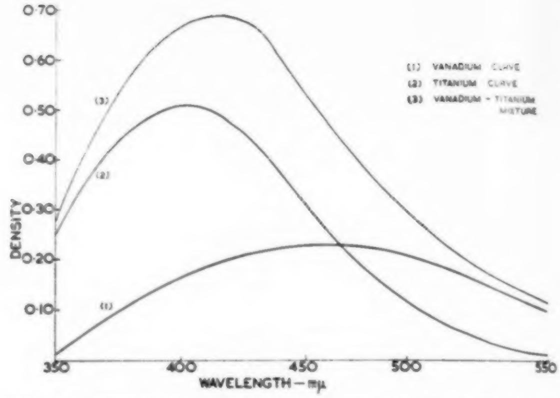


Fig. 6.—Density v. wavelength curves for vanadium and titanium peroxy-complexes (concentration of each 40 mg./litre; 1 cm. cell).

each four-cell cycle, and it is felt that it will be the first part of the instrument to fail. The performance of the instrument using a 12 volt accumulator was not examined as the transformer supplied was found to be entirely satisfactory. It must be mentioned that the lamphouse was said by the makers to be only partially effective in counteracting the cooling effect of draughts on the filament. To test its efficiency in practice, a strong artificial stream of air, directed at the lamphouse while the instrument was in operation, did not affect the position of the microammeter needle, so that the screening of the lamphouse may be taken as completely adequate.

If, for any reason, such as damage to the optical alignment or failure of the photocells, the sensitivity of the system were reduced, this would not be appreciated whilst compensation could be made by widening the slit. This would give an unduly wide bandwidth and could lead to highly erroneous results without any indication to the operator of failure, as the slit control is not calibrated in any way.*

The red and blue photocells are both in circuit when the instrument is in operation, and the changeover from one photocell to the other (at about 610 mμ) is effected by a simple control operating a plane mirror. There is an almost complete absence of variation in dark current on changeover.

Conclusion

The ease of operation and stability of the instrument make it ideal for the measurement of transmission curves in connection with the development of new and improved colorimetric procedures in the metallurgical industry. It is, perhaps, preferable to a large quartz spectrophotometer for investigational work except where it is required to work in the ultra-violet region of the spectrum.

The consistency between the density scales of the Unicam S.P.600 and the Spekker shows that if the optimum wavelength can be obtained from a filtered mercury lamp the balanced circuit feature and general simplicity of a filter absorptiometer may be advantageous in long term practice. The essential advantage of the Unicam S.P.600, however, lies in the freedom of choice of wavelength used, and if the instrument is considered as a simple absorptiometer, this single factor of wave-

* The next batch of instruments will be fitted with a slit width control calibrated in arbitrary units. This will be available for existing spectrophotometers.

length selection will give improved results on existing methods of macro- and micro-analysis. The narrow bandwidth also greatly facilitates the determination of trace elements when selectivity must be at a maximum. In the authors' opinion, the only serious drawback to the instrument is the awkwardness of the cell carriage, which does not make for rapid routine operation. They understand however, that the manufacturers are considering re-designing their test tube holder (supplied as an optional accessory) to facilitate routine works analysis.

For the small metallurgical laboratory where analytical research, determination of trace elements, and micro-chemical analysis are being carried out, the Unicam S.P.600 spectrophotometer has much to commend itself: it has been applied in these fields in both the authors' laboratories.

Acknowledgments

The authors wish to express their thanks to the manufacturers, Unicam Instruments (Cambridge), Ltd., for the loan of the instruments for the initial tests. Figs. 1, 2 and 7 are reproduced by courtesy of the Unicam Company. The authors also wish to thank colleagues in both laboratories who assisted in the practical examination of the instrument. They are indebted to Mr. J. L. Craggs (Bragg Laboratory) for the preparation of Figs. 3 and 4 and to Mr. W. R. Nall (Bragg Laboratory) for many useful comments.

Fig. 7.—General view of the S.P.600 spectrophotometer.

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2 B.I.S.R.A. Methods of Analysis Committee, "Physical Aspects of Absorptiometric Analysis," Iron and Steel Institute Special Report No. 55, 1956, p. 24.
3 B.I.S.R.A. Methods of Analysis Committee, ibid., p. 4.
4 British Standard 1121: Part 30: 1954—Cobalt in Iron and Steel.

Self-Controlling Silver Etch

A DESIRE for economy and convenience in the etching of silver led Philip F. Kurz and his colleagues at Battelle to develop a self-controlling etching process. Their purpose was to clean and prepare silver surfaces for further chemical treatment. As developed, the process involves the use of a 3% aqueous solution of nitric acid containing 0·4% sodium nitrate. The technologists found that the attack of the solution on silver was rapid, but not violent, during the first minute of boiling. At the end of three minutes the etching was almost complete, and appeared to be complete after five minutes of boiling. No further action of the acid on the silver was visible even after boiling for an additional 55 minutes (water was added periodically to keep the volume essentially constant). The process was used successfully with silver foil and sheet ranging from one to ten mils in thickness, and with up to 100 sq. in. in superficial surface area.

Thermal Conductivity of Grey Iron

THE thermal conductivity of grey iron is a property that often deserves greater consideration than it receives from designers and engineers. As noted below, such conductivity may be of critical importance, and grey iron cannot always be replaced satisfactorily by other materials that have greater strength, but lower thermal conductivity. Indeed, grey iron's ability to conduct heat may, in some cases, be a more important factor to consider than its lack of strength.

In their paper before the Grey Iron Division of the American Foundrymen's Society, J. A. Davis, H. W. Deem, and H. W. Lownie, Jnr., of Battelle, have listed situations in which thermal conductivity may be a significant factor to consider. These situations are where:—

(*a*) The flow of heat is unsteady or cyclic; thus one face of a coating may be alternately heated and cooled, as on the hot face of the pistons in a two-cycle engine.

(*b*) Metal sections are thick, as in the water-cooled rolls used to form glass.

(*c*) There is rapid transfer of heat to the iron or away from the iron, as when the surface of a brake drum is heated by friction.

(*d*) There is a fairly large difference in temperature between the hot and cold faces of the casting.

Thermal conductivity may also have an important effect on the performance of equipment in certain applications, as when it is desired to: (1) transfer heat through the iron so as to do a job on the cooler side of the casting wall; and (2) transfer heat through the iron so as to get it away from a hot face. Thus in the first case, lower conductivity may result in less heat where it is needed. In the second type of application, failure to get heat away fast enough may increase tendencies for the heated face of a casting to warp, heat check, oxidize, or grow.

Crown Spring Company Move

MANUFACTURING sections of the Crown Spring Co., Ltd., (a subsidiary of Geo. Salter & Co., Ltd.), are being transferred from premises in Littleton Street, West Bromwich, to the new Salter factory at Spring Road, Smethwick. This will allow Crown Spring customers to take advantage of the latest spring production machinery and processes which are installed in the Salter factory. All workpeople affected by the transfer will also be moving into the new factory.

Direct Study of Crystal Lattices and Their Imperfections

SOON after the discovery of X-rays, it was found that a crystal placed in the path of an X-ray beam will divide it into a number of " reflected " beams, the intensities and directions of which vary from one substance to another. Measurements on these reflected beams tell us that the atoms of which the crystal is built are arranged in a highly regular three dimensional lattice, the distance between the atoms being between 10^{-7} and 10^{-8} cm.

The distance is so small that we cannot hope to see the individual atoms or molecules in an ordinary optical microscope, since this will allow us to see only detail of dimensions about 10^{-4} cm. or slightly less, at a magnification of perhaps 2,000 times. In order to resolve smaller details, we must turn to the electron microscope. One of the latest models of this instrument, developed by Professor Ruska, the original inventor, offers the possibility of obtaining photographs of crystals at a magnification of 1,500,000, showing detail of dimensions smaller than 10^{-7} cm.

Using one of these microscopes at Tube Investments Research Laboratories, Hinxton Hall, Cambridge, Dr. J. W. Menter has succeeded in imaging directly the lattice of a crystal in which planes of molecules are spaced 10^{-7} cm. apart. The distance between them, measured directly from the photographs, agrees closely with the value previously deduced by the indirect methods of X-ray diffraction.

Organic Crystal Specimens

The materials photographed are copper and platinum phthalocyanine, whose molecules consist of a ring of organic material surrounding a central metal atom (copper phthalocyanine is the well known blue paint pigment, Monastral Blue). Very thin crystals of these materials have been prepared and examined by directing the electron beam of the microscope through them. Under these conditions, in the orientation chosen, a particular set of crystal planes separated by 10^{-7} cm. in copper phthalocyanine and by $1 \cdot 2 \times 10^{-7}$ cm. in platinum phthalocyanine is seen edge on.

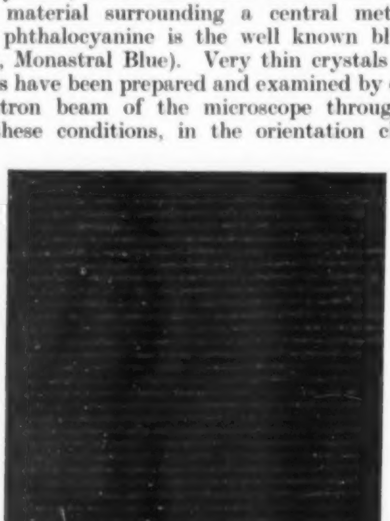

Fig. 1.—Electron micrograph of part of a crystal of platinum phthalocyanine, showing plans of molecules $1 \cdot 2 \times 10^{-7}$ cm. apart. $\times$ 1,500,000

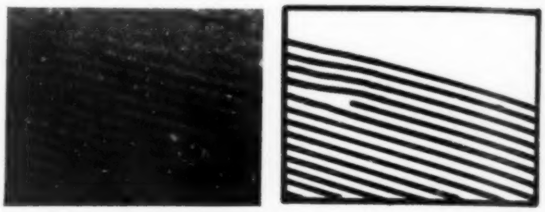

Fig. 2.—(a) Electron micrograph of part of a crystal of platinum phthalocyanine, showing imperfection in structure ; (b) sketch copied from the micrograph, showing exact position of imperfection. $\times$ 1,500,000

Fig. 1 is a picture of a platinum phthalocyanine crystal obtained in this way, at a magnification of 1,500,000. Ideally, the image of the crystal lattice viewed in this orientation should consist of a rectangular array of dots, but this is not obtained because the spacing of the molecules along the lines in the photograph is too small to be distinguished, even with this microscope. In some other crystals, where the distance between the planes of molecules in two directions is within the resolution limit of the microscope, arrays of dots have been seen.

Direct Evidence of Dislocation

This demonstration that it is now possible to obtain a direct image of a crystal lattice opens up entirely new vistas for the study of the properties of solids. More than twenty years ago it was shown by Sir Geoffrey Taylor that the comparative weakness of crystals was explicable on the assumption of a limited number of imperfections of a particular type, called dislocations, in an otherwise perfect crystal lattice. Hitherto, evidence for their existence had been very indirect, but already this new method of studying crystal lattices has shown that these imperfections may be photographed directly.

Fig. 2 is a picture of a dislocation in a platinum phthalocyanine crystal. The accompanying sketch, showing the nature of the dislocation more clearly, has been copied from the photograph. The dislocation is formed where one of the planes of molecules terminates inside the crystal and its immediate neighbours continue to grow and join up again, so that the spacing of the crystal planes at some distance from the dislocation is uniform. Near the dislocation, however, the lattice is considerably strained, since the regular lattice structure is disturbed, exactly as had been suggested in Taylor's theory.

One of the main objects of contemporary research into the properties of solids is to try to understand the plastic, strength, fracture, fatigue, and creep properties in terms of the movement of imperfections of the type illustrated. Now that it is possible to see these imperfections directly, it should be possible to study their movement under stress by recording cine photographs.

A Rapid Method of Estimating the Fatigue Limit or Endurance Limit of Metals in Reverse Bending*

By J. McKeown, D.Sc., M.I.Mech.E., F.I.M.†

(*Communication from The British Non-Ferrous Metals Research Association*)

An account is given of an investigation of a rapid method of estimating the endurance or fatigue limit of a material, using a progressive loading technique. The method appears to hold considerable promise, except possibly in the case of materials which are unstable in the conventional fatigue test, e.g., some of the aluminium alloys. It is suggested that the method might find its most important application in determining the effect of changes in design in improving or detracting from fatigue performance.

In the conventional method of determining the endurance limit or fatigue limit of a material, a number of specimens are subjected to successively lower ranges of reversed stresses and the endurance, or number of stress cycles to failure, determined. The number of specimens used depends on the material and the scatter of results obtained or expected from it, but is seldom less than ten. The endurance curve obtained by this method requires a considerable time for its determination ; thus at a speed of 3,000 cycles of stress per minute an individual test run to 100 million cycles requires a time of approximately 23 days. Even when only one of the specimens is run to a life of 10^8 cycles, the determination of the complete endurance curve will take a time of at least eight weeks, using one machine. With more machines the time required can, of course, be reduced, but not below something of the order of four weeks.

Many attempts have been made, and continue to be made, to reduce this testing time. One obvious way is to increase the speed of the testing machine, but when this is done there is always present an element of doubt as to whether or not the endurance limit determined is dependent on speed. Some recent work[1] by Forrest and Tapsell has shown that the shape of the endurance curve is dependent on speed over the range 10 to 8,000 cycles per minute in the case of a normalised 0·17% carbon steel. A critical review of the various other short time methods which have been proposed and tried from time to time has been made by Vidal,[2] who concluded that none of them was really satisfactory.

Of the various types of short time test used in the past, that developed by Prot[3,4] in 1948 has aroused the greatest interest. In this method the load is increased progressively until the specimen breaks, the test being repeated on a number of specimens at different rates of increase in load. When the breaking loads in the tests are plotted against the square root of the corresponding rates of increase of load, the points are found to lie on a straight line, the intersection of this line with the load axis through zero rate indicating the fatigue limit. The total testing time depends on the number of specimens used, and in general is of the order of one to two weeks.

The Prot method has been investigated by Corten, Dimoff and Dolan,[5] and also by Ward, Schwartz and Schwartz,[6] who found it promising for rapid estimation of the endurance limit of ferrous metals which have well defined fatigue limits. Results obtained on some light alloys were not so convincing, and further investigations are proceeding.

The present author thought it well worth while to determine whether there was a good enough correlation between the endurance limit and the result of a single progressive load test to enable the latter type to be used as a sorting test at least. It seemed desirable to adopt a rate of loading which would cause fracture in not less than about half a million cycles, because inspection of many conventional endurance curves for different materials showed that the stresses producing fracture in fewer cycles were not always in the same order as those producing fracture in 10^7 cycles or more.

In the present test, therefore, the stress on the specimen is increased at one constant rate until fracture occurs. To be entirely logical, that rate might be adjusted to produce fracture in the same number of cycles for each material, but such a procedure would complicate the testing equipment and would require exploratory test to determine the appropriate rate. Consequently, in the simplified procedure adopted here, a rate of loading was arbitrarily chosen for a group of materials with endurance limits (50×10^6 cycles) of the order $\pm$ 10 tons/sq. in., or more, while other lower arbitrarily chosen rates were used for weaker materials. The stress producing fracture is termed the dynamic breaking stress, and the present paper records the relationship between its value and that of the known endurance limit of the material.

For steels, copper-base alloys, lead-base alloys and magnesium-base alloys, the relationship appears to be a linear one, but the slope of the line is different in the different systems. In the case of aluminium-base alloys, the scatter of results obtained indicates that some disturbing factor, possibly structural instability, is operating, and these materials will require further investigation.

Description of the Test

The tests so far made have all been carried out on Wöhler type rotating bending machines running at a speed of approximately 3,000 r.p.m. The rotating specimen is loaded as a simple cantilever by means of a calibrated spring, as shown in Fig. 1. The spring is extended by rotating the nut N on the screw S at a constant fixed rate, through a worm gear driven by the

* The work described in this paper was made available to members of the B.N.F.M.R.A. in a confidential research report (R.R.A. 1082) issued in May, 195

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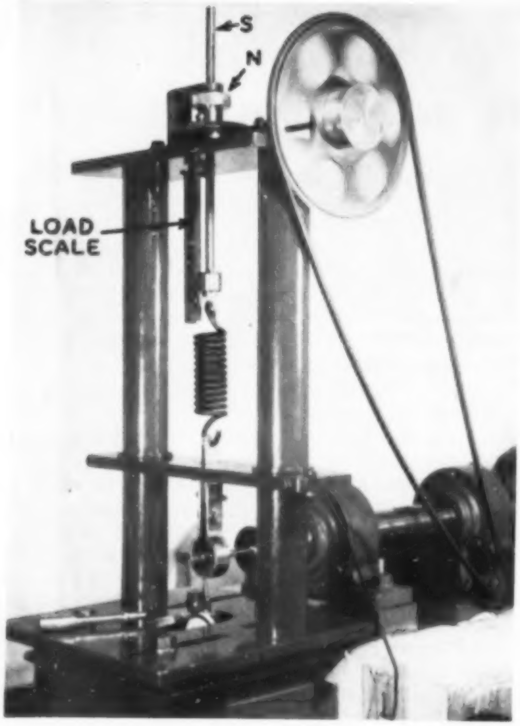

Fig. 1.—Arrangement of rapid test equipment on Wöhler machine.

machine itself. Thus the load on the specimen is progressively increased at a constant fixed rate from zero until fracture occurs. When this happens, a simple trip mechanism stops the driving motor of the machine, and the spring load at the moment of fracture is read off the scale, enabling the breaking stress to be calculated.

The test piece used in the tests on the lead alloys had a diameter of 0·3370 in. and a bending arm of 0·750 in. For the tests on the copper-base alloys, the steels, the magnesium-base and the aluminium-base alloys, the test piece had a diameter of 0·3125 in. and the bending arm was 1·89 in.

TABLE I.—TENSILE STRENGTH, ENDURANCE LIMIT, AND DYNAMIC BREAKING STRESS IN RAPID FATIGUE TESTS ON COPPER-BASE ALLOYS.

Material	B.N.F. Mark	Tensile* Strength (tons/sq. in.)	Endurance Limit at 50×10^6 cycles (± tons/sq. in.)	Dynamic Breaking Stress in Rapid Fatigue Test (± tons/sq. in.)
H.C. Copper (soft)	RIA	14·8	4·85	11·5
H.C. Copper (hard)	RIB	21·0	7·1	15·0, 15·4
70/30 Brass	RIC	38·4	12·5†	25·0, 25·8
Chromium Copper (0·5% Cr)	RID	30·5	8·8	17·6, 19·5
Leaded Brass (58% Cu, 40% Zn, 2% Pb) ..	RIE	32·3	12·0†	24·2, 24·7
5% Tin Bronze	RIF	37·0	14·0	27·5, 27·9
8% Tin Bronze	RIG	39·8	14·5	29·6, 30·1
Tungum Alloy (85% Cu, 12% Zn, 1% Al, 1% Ni, 1% Si)..	RIH	41·4	13·0	26·2, 26·8
D.T.D. 197A (10% Al, 5% Fe, 5% Ni)	RII	55·0	19·5	38·3, 41·5

* Obtained on short test pieces (½ in. parallel length) machined from large ends of broken rapid fatigue test pieces, diameter of parallel portion being the same as diameter of the fatigue test pieces.

† Stated by supplier of material to be typical value.

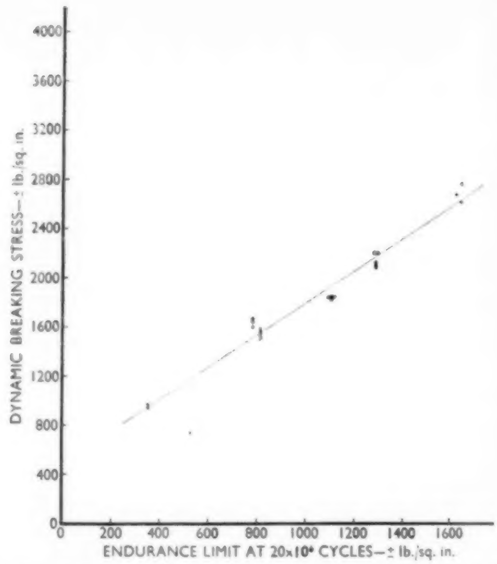

Fig. 2.—Relation between dynamic breaking stress and endurance limit for lead alloys.

Results of Tests

Lead and Lead Alloys

In the test on these materials, a light spring was used in conjunction with a short specimen. The rate of increase of stress was approximately 200 lb./sq. in./hr., corresponding to 1,130 lb./sq. in./10^6 cycles.

The materials tested covered a range of lead alloys which had been produced during one of the Association's researches and the endurance limits of which had been previously determined on a basis of 20×10^6 cycles.

A plot of dynamic breaking stress against endurance limit is given in Fig. 2 and the relationship is seen to be a linear one. At an earlier stage of the work, the results for lead and lead alloys had been found to give a relationship which was not quite linear. Further investigation showed, however, that this was due to changes having occurred in some of the materials between the time when endurance limits had been determined and that when dynamic breaking stresses were obtained.

Copper and Copper Alloys

Nine copper alloys, ranging from high conductivity copper in the annealed condition to the complex aluminium bronze to D.T.D.197, were obtained through the kindness of a member company. The details of these materials are given in Table I. Some of the endurance limits given in the table were stated by the supplier to be typical values for the particular materials. Approximate values of the endurance limits of some of the other materials have been determined from endurance tests on specimens cut from the bars supplied.

The heavier spring (rate 147 lb./in.) shown in Fig. 1 was used in these tests, and the rate of stressing was 4·45 tons/sq. in./hr., which is equal to 25·1 tons/sq. in./10^6 cycles. Duplicate tests were made on eight of the materials, and a single test only on the annealed high conductivity copper. The results obtained are shown in Fig. 3, from which it will be seen that the points fit the straight line drawn, and also that there was good reproducibility in the duplicate tests.

TABLE III.—TENSILE STRENGTH, FATIGUE LIMIT AND DYNAMIC BREAKING STRESS IN RAPID FATIGUE TESTS ON THREE EN SERIES STEELS.

Material	B.N.F. Mark	Heat Treatment	Tensile* Strength (tons/sq. in.)	Fatigue Limit (± tons/sq. in.)	Dynamic Breaking Stress in Rapid Fatigue Test (± tons/sq. in.)
B.S.970 En8	RIT	Air cooled from 850° C. (1 hr.), tempered 1 hr. at 600° C.	40·8	19·6	29·0
B.S.970 En8	RIV	Air cooled from 880° C.	41·3	21·9	30·1
B.S.970 En9	RIU	Oil quenched from 830° C. (1 hr.), tempered 1 hr. at 600° C.	56·5	26·5	35·5
B.S.970 En100	RIS	Oil quenched from 850° C. (1 hr.), tempered 1 hr. at 625° C.	62·0	34·4	44·2

* Tensile properties provided by supplier of steel.

Steels

Through the courtesy of the research department of one of the major steel companies, and also of the British Iron and Steel Research Association, a number of short lengths of steel were obtained, the fatigue limits of which had actually been determined on other parts of these lengths. The heat treatments of these steels were carried out on the materials for the rapid tests at the same stage of the production of specimens as was used for the conventional fatigue tests. Details of chemical analyses and heat treatments are given in Tables II and III.

The results obtained in the progressive loading tests at a rate of stress increase of 25·1 tons/sq. in./10^6 cycles are plotted against the fatigue limits in Fig. 4, and it is seen that, with the exception of the two 3% nickel-chromium steels, the points lie very well on a straight line. The slope of this line is different from that of the line in Fig. 3, for the copper alloys.

The detailed chemical analyses and heat treatments of the two 3% nickel-chromium steels given in Table II offer no explanation of why these two steels gave results in the rapid test so different from the other steels. They differ from all the others, however, in an important respect: the endurance curves obtained in the conventional tests, when plotted as stress against logarithm of cycles, show a continued fall instead of the marked knee type of curve normally obtained with steels, i.e., they do not show a marked fatigue limit as do the other steels. It is also possible that these two steels react differently from the other steels to the understressing which occurs in the early part of the progressive loading fatigue test, i.e., they may react differently to "coaxing."

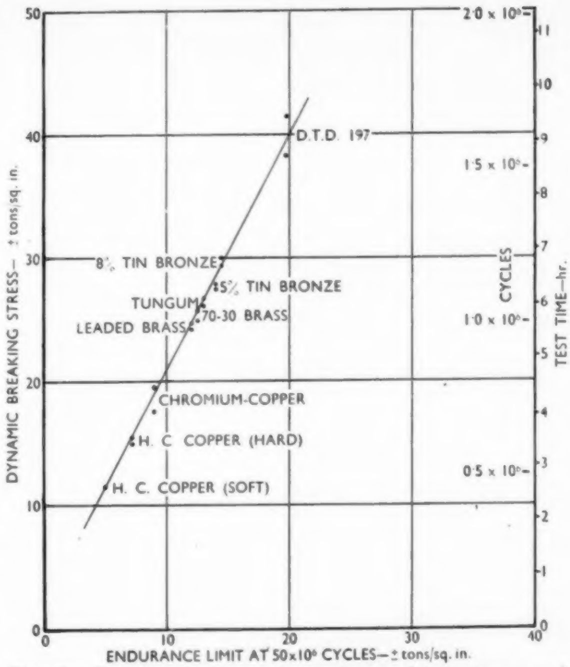

Fig. 3.—Relation between dynamic breaking stress and endurance limit for copper alloys.

Aluminium Alloys

Particulars of the materials, obtained from two

TABLE II.—COMPOSITION, MECHANICAL PROPERTIES AND FATIGUE TEST DATA FOR A RANGE OF STEELS.

Quality	0·2% C	Low C-Cr-Mo	0·35% C	3% Ni-Cr	Plain C	4¼% Ni-Cr-Mo	3% Ni-Cr
B.N.F. Mark	RHI	RHJ	RHK	RHL	RHM	RHN	RHO
Chemical Analysis							
Carbon (%)	0·21	0·10	0·35	0·11	0·71	0·15	0·14
Manganese (%)	0·70	0·42	0·64	0·45	0·72	0·43	0·48
Silicon (%)	0·20	0·22	0·19	0·21	0·23	0·135	0·25
Sulphur (%)	0·033	0·021	0·026	0·031	0·040	0·020	0·028
Phosphorus (%)	0·029	0·015	0·024	0·020	0·027	0·020	0·020
Nickel (%)	0·15	—	0·22	3·08	0·06	4·36	3·16
Chromium (%)	0·09	0·95	0·10	0·76	0·09	1·50	0·88
Molybdenum (%)	—	0·60	—	—	0·01	0·27	—
Vanadium (%)	—	—	—	—	—	—	—
Dimensions	¾ in. dia.	¾ in. dia.	¾ in. dia.	¾ in. dia.	¾ in. dia.	¾ in. dia.	¾ in. dia.
Heat treatment	Air cooled from 890° C.	Air cooled from 900° C.	Oil quenched from 860° C., tempered at 620° C.	Oil quenched from 780° C., tempered 1 hr. at 400° C.	Air cooled from 800° C.	Oil quenched from 860° C., tempered 1 hr. at 500° C.	Oil quenched from 780° C., tempered 1 hr. at 400° C.
Mechanical Properties*							
Tensile Strength (T.S.) (tons/sq. in.)	34·2	37·5	44·3	54·9	59·3	73·2	74·3
Yield Stress (tons/sq. in.)	23·7	23·7	34·3	49·7	32·8	68·3	71·1
Elongation on 2 in. (%)	36·5	31·5	27·0	24·0	26·0	19·0	16·0
Reduction of Area (%)	66·0	64·0	64·0	64·0	34·5	59·0	60·0
Izod Impact Value (ft. lb.)	76·0	65·0	79·0	56·0	6·0	43·0	17·0
Fatigue Properties							
Type of Machine	Uniform Bending Moment	Rotary Cantilever	Uniform Bending Moment	Rotary Cantilever	Rotary Cantilever	Rotary Cantilever	Rotary Cantilever
Limiting Fatigue Stress (L.F.S.) (± tons/sq. in.)	16·3	19·25	22·25	28·0	27·25	37·0	35·5
Fatigue Ratio (L.F.S./T.S.)	0·47	0·51	0·50	0·51	0·46	0·51	0·48
Dynamic Breaking Stress in Rapid Fatigue Test (± tons/sq. in.)	25·3	27·0	31·8	42·3	36·3	48·2	53·0 51·8

* Mechanical properties provided by supplier of steel.

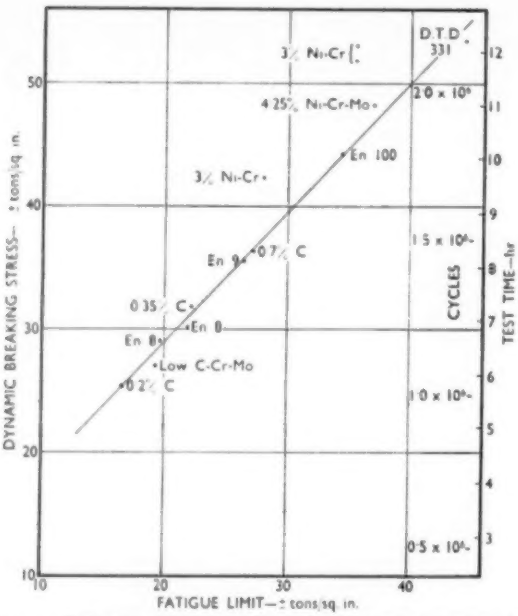

Fig. 4.—Relation between dynamic breaking stress and fatigue limit for steels.

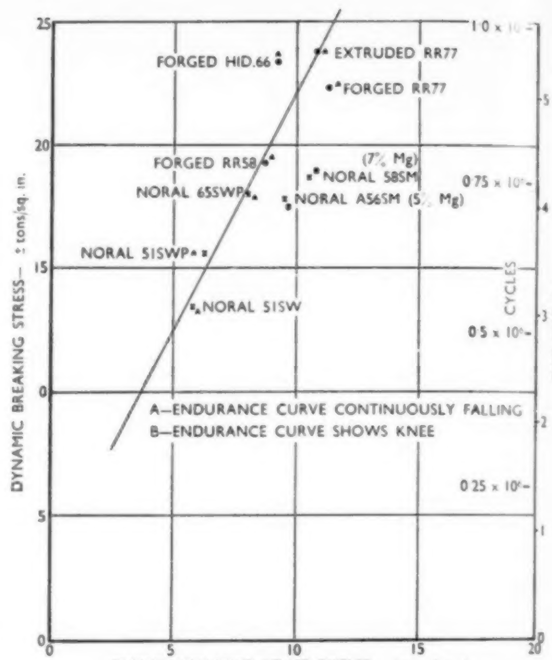

Fig. 5.—Relation between dynamic breaking stress and endurance limit for aluminium alloys at fast rate of stress increase.

member companies, are given in Table IV. The endurance curve obtained on samples from the same bar was provided for each of the materials.

The dynamic breaking stresses were firstly determined at the same rate of increase of stress as was used in the tests on the steels and on the copper alloys, and the results obtained are shown in Fig. 5. An additional point was obtained using a fully heat treated specimen of the Noral 51 material, the endurance limit in this condition being stated to be $\pm$ 6·2 tons/sq. in. It is seen that a reasonable straight line fits all the points with the exception of the two Noral alloys 58 SM and A 56 SM. These two materials contain, respectively, 7% and 5% magnesium, and it is of interest to note that these two materials give the steel type of endurance curve, i.e., the curve showing a marked knee and hence a fatigue limit. All the other materials show endurance

TABLE IV.—TENSILE STRENGTH, ENDURANCE LIMIT AND DYNAMIC BREAKING STRESS IN RAPID FATIGUE TESTS ON ALUMINIUM-BASE ALLOYS.

Material	Specification	B.N.F. Mark	Tensile* Strength (tons/sq. in.)	Endurance Limit at 10^8 cycles ($\pm$ tons/sq. in.)	Dynamic Breaking Stress in Rapid Fatigue Test ($\pm$ tons/sq. in.) Rate of Stress Increase: 4·45 tons/sq. in./hr.	0·5 tons/sq. in./hr.
Forged RR77 ..	D.T.D.683	RHV	35·0	11·3	22·3	21·5
Extruded RR77 ..	D.T.D.683	RHW	40·5	10·8	23·8	20·9
Forged Hiduminium 66	B.S.L64	RHX	31·8	9·2	23·4	20·6
Forged RR58 ..	D.T.D.717	RHY	29·2	8·7	19·3	19·1
Noral 51SW ..	B.S.1476 HE10W	RIO	15·9	5·9	13·5	12·5
Noral 65SWP ..	B.S.1476 HE20	RIP	23·8	8·1	18·0	15·2
Noral A56SM ..	B.S.1476 NE6M	RIQ	19·0	9·5	17·8	17·3
Noral 58SM	B.S.1476 NE7M	RIR	24·8	10·5	19·7	18·2

* Obtained on short test pieces (½ in. parallel length) machined from large ends of rapid fatigue test pieces, diameter of parallel length being same as diameter of the fatigue test pieces.

curves of the type more normal for aluminium alloys in which the S-log N curve is continously falling.

In Fig. 5 the two forged materials Hiduminium 66 and RR77 do not fit too well to the line drawn, and it was therefore decided to test all the materials at a lower rate of increase of stress, namely 0·5 tons/sq. in./hr. (2·83 tons/sq. in./10^6 cycles). The results of these tests are shown in Fig. 6. It was now found that the four Noral materials fitted closely a new straight line, with the other four materials scattered to the left of this line. While at the moment no explanation of this can be offered, further work on this problem is in hand. Hanstock[8] has recently shown that precipitation may occur in some of the high strength alloys under cyclic stressing. It seems possible that the rate of precipitation would be different in the rapid and the long time fatigue tests, not only because of the different strains involved in the two tests, but also because of the different durations and cycles of strain. Further it seems likely that the rate of precipitation is different in different alloys.

At present it does not appear that the rapid fatigue test can be applied to aluminium alloys in the simple way in which it can be used for lead and copper alloys and steels. It is perhaps worth noting in passing that all the earlier types of rapid test, including the Prot test, have failed to prove satisfactory for aluminium-base alloys, and Hanstock's recent findings suggest that this was because of structural instability in the alloys under fatiguing conditions, such instability not being reproduced in the accelerated tests.

Magnesium-Base Alloys

These materials consisted of both cast and wrought alloys supplied by a member company. Magnesium-base alloys give the type of endurance curve which shows

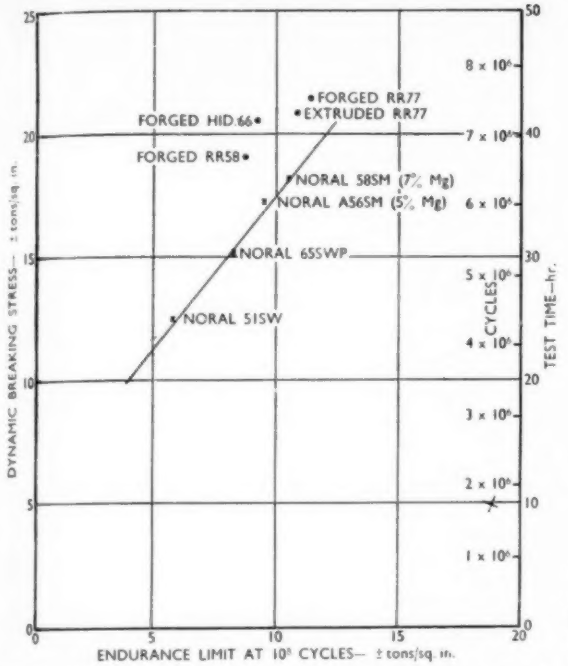

Fig. 6.—Relation between dynamic breaking stress and endurance limit for aluminium alloys at slow rate of stress increase.

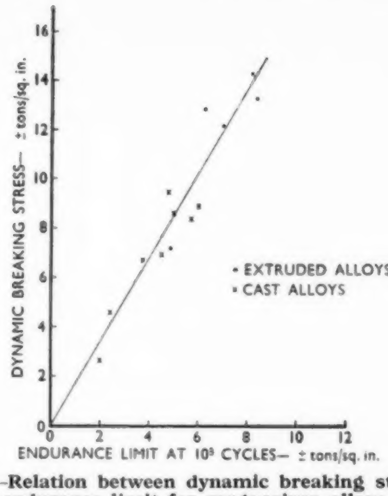

Fig. 7.—Relation between dynamic breaking stress and endurance limit for magnesium alloys.

a marked knee, and the endurance limit in general is a fatigue limit. Endurance limits at 10^8 cycles were provided for each material. The dynamic breaking stresses were obtained at the lower rate of stress increase, i.e., 2·83 tons/sq. in./10^6 cycles.

The particulars of the materials are given in Tables V and VI. The plot of dynamic breaking stress against endurance limit at 10^8 cycles is given in Fig. 7, and shows a reasonably good linear relationship to exist between these two quantities.

Reproducibility of Results in the Progressive Loading Test

Insufficient material was available for this work in any of the alloys already tested and for which endurance limits were known. The reproducibility tests had therefore to be carried out on new supplies, the endurance limits of which have not yet been determined. Aluminium-base alloys were chosen for this work.

TABLE V.—COMPOSITION OF MAGNESIUM-BASE ALLOYS.

(a) *WROUGHT MATERIALS*

Alloy	B.N.F. Mark	Zn (%)	Zr (%)	Al (%)	Mn (%)	Other Elements (%)	
ZA	RVD	0·03	0·26	0·01	0·014	Si <0·01	Cu 0·007
ZW1	RVE	1·2	0·56	0·01	0·014	Si <0·01	Cu 0·007
ZW3	RVF	3·0	0·43	0·01	0·01	Si <0·01	Cu 0·009
AZ31	RVG	0·75	—	2·9	0·44	Si <0·01	Cu <0·009
AZM	RVH	0·82	—	5·9	0·2	Si 0·03	Cu <0·03

In all Fe <0·01%, Sn <0·003%, Ni <0·003%, Ca <0·02%.

(b) *CAST MATERIALS*

Alloy	B.N.F. Mark	Zn (%)	Zr (%)	R.E. (%)	Al (%)	Mn (%)	Th (%)
Pure Magnesium ..	RTT	0·013	—	—	0·006	<0·005	—
A8 ST	RTU	0·47	—	—	8·4	0·36	—
AZ91 F.	RTW	0·54	—	—	8·8	0·28	—
RZ 5 H.	RTX	3·9	0·66	1·0	—	—	—
ZA	RTY	—	0·62	—	—	—	—
Z1½Z1RE	RUY	1·4	0·61	0·95	—	—	—
ZT1	RUZ	2·1	0·74	—	—	—	2·8
TZ6	RVA	5·9	0·74	—	—	—	1·6

The tests on any one material were all carried out on one machine so as to avoid any machine effect. Most of the tests were made at the slow rate of increase of stress, 2·83 tons/sq. in./10^6 cycles, but in one material the rapid rate, 25·1 tons/sq. in./10^6 cycles, was also used. The results obtained are given in Table VII and show that the scatter about the mean value is reasonably small, about ± 5%, being somewhat better in the slow rate of loading tests than in the fast rate. It is clearly desirable when using the new test to take a mean value obtained from two or more specimens. It may be noted that the number of cycles to failure is directly proportional to the dynamic breaking stress, and a scatter of only ± 5% in endurance in constant stress testing would normally be considered quite small.

Notched Specimens

Another laboratory has been carrying out a programme of tests on the strong titanium alloy Ti 150A, using a

TABLE VI.—ENDURANCE LIMIT AND DYNAMIC BREAKING STRESS IN RAPID FATIGUE TESTS ON MAGNESIUM-BASE ALLOYS.

(a) *WROUGHT (EXTRUDED) MATERIALS*

Alloy	B.N.F. Mark	Stated Endurance Limit (±tons/sq. in.)	Dynamic Breaking Stress in Rapid Test (±tons/sq. in.)
ZA	RVD	4·5–5·2 (4·85)	7·11, 7·26 (7·2)
AZ31	RVG	6·0–6·5 (6·25)	12·3, 13·3 (12·8)
ZW1	RVE	7·0 (approx.)	12·2, 12·1 (12·2)
ZW3	RVF	7·7–8·7 (8·2)	14·3, 14·1 (14·2)
AZM	RVH	8·0–8·7 (8·35)	13·5, 12·3, 13·9 (13·2)

(b) *CAST MATERIALS*

Alloy	Condition	B.N.F. Mark	Stated Endurance Limit (±tons/sq. in.)	Dynamic Breaking Stress in Rapid Test (±tons/sq. in.)
Pure Magnesium	As cast	RTT RVP	2·0	2·12, 3·0 2·73 (2·6)
A8-ST	Solution treated 8 hr. at 385° C. + 16 hr. at 420° C.	RTU	5·7	7·53, 9·17 (8·4)
AZ91-FHT	Solution treated 8 hr. at 385° C. + 16 hr. at 420° C. + 12 hr. at 200° C.	RTW	4·8	10·1, 8·75 (9·4)
RZ-HT	2 hr. at 330° C. + 16 hr. at 180° C.	RTX	6·0	8·82, 8·93 (8·9)
ZA	As cast	RTY	2·4	4·85, 4·25 (4·6)
Z1½Z1RE	As cast	RUY	3·75	6·62, 6·77 (6·7)
ZT 1	16 hr. at 315° C.	RUZ	4·5	7·0, 6·84 (6·9)
TZ6	2 hr. at 330° C. + 16 hr. at 180° C.	RVA	5·0	8·62, 8·52 (8·6)

TABLE VII.—REPRODUCIBILITY TESTS AT SLOW AND FAST RATES OF PROGRESSIVE LOADING.
(Materials all in the Fully Heat Treated Condition).

Material	Loading Rate	Dynamic Breaking Stress (± tons/sq. in.)	Mean Dynamic Breaking Stress (± tons/sq. in.)	Scatter % About Mean Value
Extruded RR77 ..	Slow	19·7, 21·4, 21·3 21·1, 20·3, 22·1	21·0	+2, −6
Forged RR77	Slow	20·0, 19·5, 18·0 19·4, 19·6, 18·5 19·6, 18·5	19·1	+5, −3
Forged Hiduminium 66	Slow	18·8, 18·6, 19·0 18·2, 18·4, 19·7 18·5, 18·9	18·8	+5, −3
Forged RR58	Slow	17·2, 17·6, 16·9 17·7, 16·6, 16·8 16·9, 17·1	17·1	+3, −3
Forged RR58	Fast	21·4, 22·9, 21·5 21·4, 20·9, 19·6 22·1, 22·3	21·5	+6, −9

number of different types of notches and determining the endurance limits of plain and notched specimens. The specimens used in this work were taken from two rolled and annealed bars marked *A* and *B*, and a few specimens from a third bar marked *C* were provided for the rapid tests. Two of these specimens were plain and four notched, the details being given in Table VIII.

The progressive loading tests were carried out at the lower rate of increase of stress, i.e., 2·83 tons/sq. in./10^6 cycles, and the breaking stresses obtained are shown in Table VIII. This table also shows the theoretical and the effective stress concentration factors in the endurance tests, and the effective stress concentration factors in the rapid tests.

In Fig. 8*a* the theoretical stress concentration factors K_t are plotted against the corresponding effective stress concentration factors K_f for both the endurance tests and the progressive loading tests. In Fig. 8*b* a similar diagram is shown for the high strength aluminium alloy D.T.D.683. Only single specimens were available for each size of notch.

It is unfortunate that only single specimens were available for the progressive loading tests in each material. The endurance test effective stress concentration factors were determined for each material from endurance curves, which naturally take into account scatter of test results, and clearly it would have been much more satisfactory to determine the progressive loading test effective stress concentration factors as an average of at least three specimens in each case. In spite of this, both the diagrams in Fig. 8 show that the progressive loading test distinguishes notch effects in a similar way to the time consuming endurance tests. Further work on these lines is at present being carried out.

General Conclusions

From the limited amount of testing done so far on a wide range of metals, both ferrous and non-ferrous, and using data for endurance limits which in some cases are perhaps not quite reliable, the progressive loading fatigue test developed appears to hold considerable promise, except possibly in the case of materials, e.g., the aluminium-base alloys, some of which are unstable in the conventional fatigue test. Further work should be done in an attempt to clear up this case. Additional work on notch effects and on methods of carrying out the test at elevated temperatures are also called for.

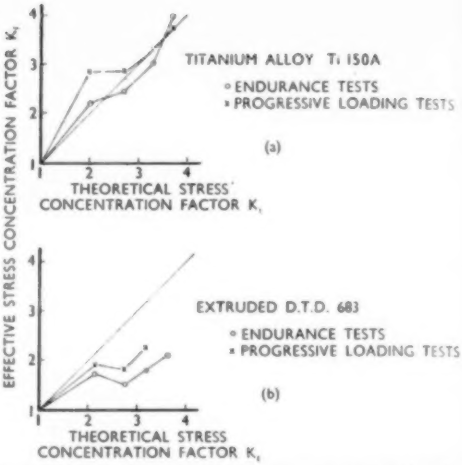

Fig. 8.—Effective v. theoretical stress concentration factors in endurance and in rapid tests.

There is, however, another aspect of this progressive loading method of fatigue testing which is possibly of much greater importance than the testing of materials to place them in relative order of fatigue resistance. This is the use of the progressive loading test principle in the assessment of the relative fatigue resistance of various designs or forms of a structural component. Frequently the effect of some changes in design of a component on its resistance to fatigue is a matter of guess-work, because of the large expenditure of time necessary to carry out a series of endurance tests on the old and new designs so as to get a comparison by endurance curves. It is reasonably clear that an improvement in fatigue resistance can be made evident by a comparison of dynamic breaking stresses in the progressive loading test described above, and, thus, if this test is applied to components, the effect of changes in design in improving or detracting from fatigue performance may be shown in quite a short time by progressive loading fatigue tests on the original and the new type of component. It is suggested that this use of the progressive loading fatigue test is one which should be thoroughly tested,

(Continued on page 158)

TABLE VIII.—ENDURANCE LIMIT AND DYNAMIC BREAKING STRESS IN RAPID FATIGUE TESTS ON PLAIN AND NOTCHED SPECIMENS OF THE STRONG TITANIUM ALLOY TI 150A.

Mark	Type of Test Piece	Endurance Limit (± tons/sq. in.)	Stress Concentration Factors		Dynamic Breaking Stress in Rapid Test (± tons/sq. in.)	Effective Stress Concentration Factor in Rapid Test (K_{f_R})	Ratio of Dynamic Breaking Stress to Endurance Limit	Cycles to Fracture in Rapid Test (÷ 10^6)
			Theoretical (K_t)	Effective (K_f)				
C13 } C14 }	Plain	36·5	1·0	1·0	{ 64·3 } Av. { 56·3 } 60·3	1·0	1·65	{ 13·63, { 11·39
C16	V-notch 0·004 in. deep	15·0	2·7	2·43	21·3	2·83	1·42	5·42
C17	V-notch 0·008 in. deep	12·1	3·3	3·02	18·4	3·27	1·52	4·70
C18	V-notch 0·020 in. deep	9·2	3·7	3·97	16·1	3·74	1·75	4·135
C19	Semi-circular notch 0·020 in. radius	16·7	2·0	2·19	21·2	2·84	1·27	5·40

The V-notches all had a root radius of 0·004 in. Diameter of plain specimens and core diameter of all notched specimens, 0·250 in.

A Direct-Reading Phase Counter for Metallurgical Specimens

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The determination of the proportions of the different phases visible on microscopic examination of a polished and etched section of an alloy resolves itself into a comparison of areas or of the length of intercepts in a linear traverse. Equipment for simplifying this operation, based on the measurement of the intercept of one phase only in a linear traverse, is described.

THE problem of determining the proportions of the different bodies present in a heterogeneous mixture is encountered in a variety of fields and can be tackled in a number of ways. In metallurgy we are concerned with plane polished sections of alloys, and the problem becomes one of comparing the areas of the phases visible under the microscope, or of the lengths of intercepts in a linear traverse. The direct measurement and summation of areas and line intercepts is a tedious business, and various pieces of equipment for use in conjunction with the microscope have been evolved to lighten and simplify a rather dull task. These devices, variously described as "phase counters," "point counters" and so on, enable the proportion of a number of phases (in some cases as many as six) to be determined simultaneously, and are useful pieces of equipment for the research worker to have at his command.

In metallurgy, measurements of the type with which we are concerned are only made to a limited extent for purposes other than research. There are, however, some instances where phase counters are useful in a more practical sense, and hence find regular employment in industrial laboratories. The author's Company, for example, is concerned with the manufacture of important engineering castings in high tensile brass (manganese bronze), a class of material calling for a rigid control of composition if uniform mechanical properties are to be obtained. There is, however, a quite close link between the structural make-up of the alloy as seen under the microscope, its composition as disclosed by analysis, and its mechanical properties. Much useful information can, therefore, be obtained by determining the proportional balance between the phases present: this can be done quickly and non-destructively.

The high strength manganese bronzes are essentially two-phase (*alpha* + *beta*) alloys, as the only other (iron-bearing) phase present constitutes so small a proportion of the whole as to be negligible. A two-phase alloy lends itself to a simpler treatment, in so far as the counting operation is concerned, than do more complex alloys, and there is obviously no call for a multiplicity of counting channels. Simple attachments for fitting to the microscope stage and working on the line-intercept principle have been described by Shand[1] and by Callis and Moore,[2] that devised by the latter authors being evolved specifically for use with manganese bronzes. Apparatus of this type, although accurate, is still rather tedious to use: it involves the reading of micrometer thimbles and verniers and, finally, the application of simple arithmetic. It occurred to the present author that

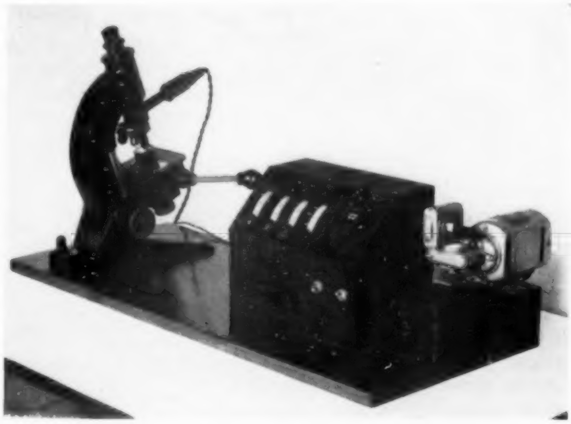

Fig. 1.—Apparatus set up for phase counting. Left: Rosenhain microscope; centre: counter mechanism; right: driving motor with control rheostat below.

a direct-reading instrument working on this same line-intercept principle was feasible, and as an aged but good microscope which could be set aside for this particular purpose was available, the apparatus was constructed and put into use. Experience has shown it to be a practical and useful piece of laboratory equipment, and this is held to justify the present description of yet another phase counter.

Principle of Operation

The determination is based on the measurement of the intercept of one phase only in a linear traverse, this being expressed as a proportion of the whole.

A small electric motor is arranged to drive the cross slide of the microscope, steadily and at a slow speed, via a high reduction gear-box and counter mechanism. The metallurgical specimen is mounted on the slide by spring clips in the usual way, and specimen and cross wires adjusted for focus. The motor is started and the speed of traverse adjusted to suit the microstructure of the specimen (fine or coarse) and the magnification used. The equipment is then set to make a steady traverse over a predetermined distance, the operator observing continuously through the eyepiece and pressing (and keeping pressed) a key while each transit of a selected phase is made. A summation of the lengths of the individual intercepts of the selected phase only is made by friction count wheels operated by the driving shaft,

and at the end of the sequence is indicated directly as a percentage of the whole traverse.

Description of Equipment

The equipment is illustrated in Fig. 1. The geared fractional horse-power motor used is of the universal type and, with full mains voltage applied, runs with a final shaft speed of 1 r.p.m. The motor is directly coupled to the screw operating the cross slide of the microscope by means of a driving shaft fitted with universal joints to allow for the rise and fall of the stage. The pitch of the operating screw is 1 mm., and the motor running at its maximum speed gives a rate of traverse suitable for dealing with coarse structures and low magnifications. For fine structures and high magnifications the speed is reduced by means of a rheostat.

Counting is effected by bringing friction wheels integral with the actual indicating wheels into contact with friction wheels on the main drive shaft. The count wheels, which are engraved on their edges and provided with knurled rims for setting purposes, are carried in swinging frames, and the movement of these frames to bring the wheels into contact is effected directly by finger pressure on the key on the front of the case. The running clearance between the wheels in their "free" position is approximately $\frac{1}{16}$ in.; a small movement only is required to effect contact, and there is no loss of time.

Provision is made for counting over three set distances —1, 2 and 5 mm., corresponding to 1, 2 or 5 complete turns of the drive shaft. So that the instrument shall be direct-reading using any one of these distances, and to avoid some other complications, three separate pairs of count wheels are provided, only one pair of which is used at any one time. Each pair comprises a friction wheel and an indicating wheel, the ratio diameter-of-drive : diameter-of-driven being 1 : 1, 1 : 2 and 1 : 3. The operating key moves in a gate and can be made to bear on any one of the three count wheels. When not in contact with their driver, the indicating wheels are held from rotation (by vibration or otherwise) by light friction from a spring washer. The friction drive wheels are cork covered and ground accurately to size and to a smooth surface.

A signal bell is provided which is struck once on each revolution of the driving shaft. A count over a 1 mm. traverse is therefore made, starting on one stroke of the bell and terminating on the next: over 2 mm. starting on the first stroke and stopping on the third, and so on. To avoid unnecessary waiting before making a count, provision is made for moving the timing wheel which operates the bell relative to the main shaft. The timing wheel is identical in shape and size with the indicator wheels, and, like them, is brought to the front of the casing and provided with a knurled rim for easy manipulation. The timing wheel is friction driven from the main shaft via 1/1 spur gearing and a friction disc.

The driving mechanism is permanently connected to the lead screw of the microscope stage. Counts are made to the right and left, the motor being reversed electrically to enable this to be done. Two sets of figures 0–100 and 100–0 (distinguished by colour) are engraved on the edges of the three count wheels so that the instrument is direct-reading in both directions. An indicator driven by means of a worm and worm-wheel from the main shaft is provided, to show at any time how much travel is possible to right or left: this indicator also operates the limit switches which prevent an overrun in either direction.

In using the instrument, the first step is to select objective and eyepiece lenses to suit the specimen to be dealt with. The motor speed is then adjusted by means of the rheostat, and the indicating wheels set to zero. The operating key is then moved into the slot appropriate to the distance over which the count is to be made. The timing wheel is then moved by hand to a position indicated by an arrow, so that after the lapse of only a few seconds the bell will ring and counting can commence. The operator is now free to concentrate on the slowly moving image. Having previously decided which of the two phases is to be counted (usually the *alpha*-phase in a manganese bronze) he will be ready when the bell rings to begin the counting operation, depressing or releasing the key as phase boundaries are traversed. At the end of the count (indicated by the bell), the count wheel is read directly as a percentage. Further counts may be made for checking purposes in the same direction (within the limits set by the permissible travel of the microscope stage) or in the reverse direction using the same procedure.

It will be appreciated that, although for the particular purpose for which it was designed the apparatus is required to determine the proportion of one phase only (the other being obtained by difference), it could be used to determine separately the proportions of three or more phases in a complex alloy.

Acknowledgments

The author is indebted to the directors of J. Stone & Co. (Charlton), Ltd., for permission to publish this description, and acknowledges with pleasure the help given by Mr. F. M. Frye in regard to detailed design. The apparatus was made in the laboratory workshop under the control of Mr. F. J. Dunning.

Rapid Estimation of Fatigue Limit

(*continued from page* 156)

because of its great potential value, and work aimed at this is at present in hand in these laboratories.

Finally, it is perhaps desirable to point out that although all the testing recorded in this paper has been carried out in alternating bending, there appears to be no fundamental reason why the progressive loading test should not be equally applicable when other methods of stressing, tension/compression, tension/tension, reversed torsion or any combination of stressing is employed.

Acknowledgments

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